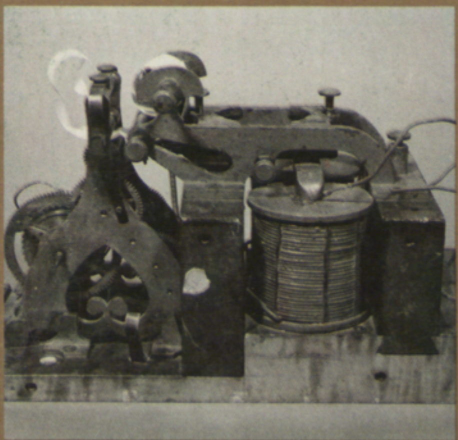
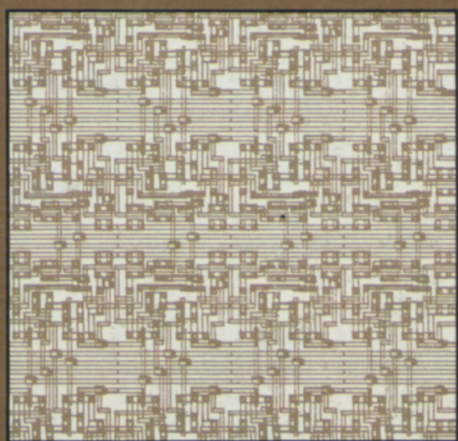
ENGINEERING

CORNELL QUARTERLY





VOLUME 19
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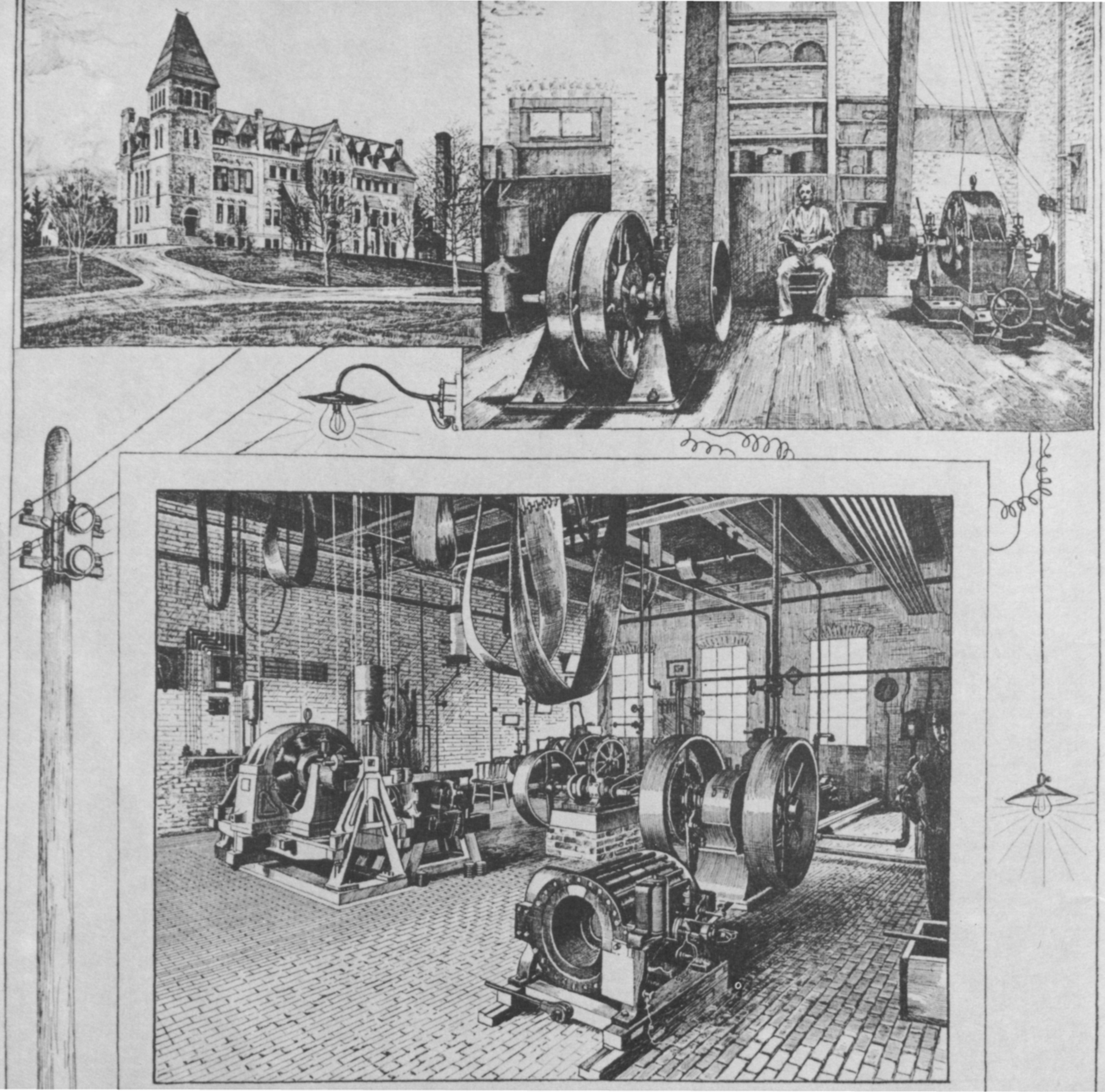
THE CENTENNIAL OF ELECTRICAL ENGINEERING



IN THIS ISSUE

Engineering: Cornell Quarterly (ISSN 0013-7871), Vol. 19, No. 4, Winter 1984-85. Published four times a year, in summer, autumn, winter, and spring, by the College of Engineering, Cornell University, Campus Road, Ithaca, New York 14853. Second-class postage paid at Ithaca, New York, and additional offices. Subscription rate: $6.00 per year; $9.00 outside the United States.

Opposite: "Views in the Department of Electrical Engineering of Sibley College, Cornell University," as published in The Electrical World *in 1890. The engravings depict Franklin Hall and the dynamo laboratory.*

Cover illustrations: the original Morse telegraph receiver (now in the possession of the Cornell College of Engineering), forerunner of a technology that Ezra Cornell helped develop; the medal awarded to three Cornell professors in recognition of their accomplishment in building the first dynamo in the United States; Cornell researchers testing an early model of a full-wave mercury-vapor power rectifier; the antenna at the Arecibo radar-radio observatory; part of a 4-micrometer field-effect transistor designed at Cornell by means of computer graphics.

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24

24

32

45

CENTENNIAL SYMPOSIUM SPEAKERS

Microelectronics March 15
Fairchild Hall, Stanford University, Stanford, California
Speakers:
Joel S. Birnbaum '59
Vice-president and director, Hewlett-Packard Laboratories
Alec N. Broers
Professor of electrical engineering, Cambridge University
Lester F. Eastman '53
Professor of electrical engineering, Cornell University
David A. Hodges '59
Professor of electrical engineering and computer science, University of California, Berkeley
William G. Howard, Jr.
Senior vice-president and director of research and development, Motorola, Inc.
Sonny Maynard
Director of very-high-speed integrated circuits, U.S. Department of Defense
James D. Meindl
Director, Center for Integrated Systems, Stanford University
Robert Noyce
Vice-chairman of the board, Intel Corporation

Computers April 1
National Conference Center, East Windsor, New Jersey
Speakers:
David H. Ahl '60
Editor-in-chief, *Creative Computing*
C. Gordon Bell
Chief technical officer, Encore Computer Corporation
Joel S. Birnbaum '59
Vice-president and director, Hewlett-Packard Laboratories
John Cocke
IBM fellow, IBM Watson Research Center
Peter Denning
Director, Research Institute for Advanced Computer Science, NASA
Eric Nussbaum
Assistant vice-president, Bell Communications Research

Communications April 10
Newton Marriott Hotel, Newton, Massachusetts
Speakers:
Richard E. Blahut, Ph.D. '72
IBM fellow, IBM Federal Systems Division
John V. Evans
Vice-president for research and development and director, COMSAT Laboratories
G. David Forney, Jr.
Vice-president and director, Motorola, Inc.
Paul E. Green, Jr.
Member, Corporate Technical Committee, IBM Watson Research Center
Irwin Jacobs '54
Executive vice-president, M/A-COM, Inc.
Robert W. Lucky
Executive director, research, AT&T Bell Laboratories

Atmospheric and Space Sciences April 17
Emerson Electric World Headquarters, St. Louis, Missouri
Speakers:
Ben B. Balsley
Program leader for tropical dynamics and climate, National Oceanic and Atmospheric Administration
William E. Gordon, Ph.D. '53
Professor of electrical engineering; vice-president and provost, Rice University
Tor Hagfors
Director, National Astronomy and Ionosphere Center, Cornell
Wilmot N. Hess
Director, National Center for Atmospheric Research
C. Gordon Little
Director, Wave Propagation Laboratory, National Oceanic and Atmospheric Administration
Joseph Veverka
Professor of astronomy, Cornell University

Energy for the Future April 25
Mayflower Hotel, Washington, D.C.
Speakers:
Harold Furth
Director, Plasma Physics Laboratory, Princeton University
Robert L. Hirsch
Vice-president for exploration and production research, ARCO Oil and Gas Company
Eric H. Willis
Director, Office for Energy Research, International Energy Agency
Gerald L. Wilson
Dean of engineering, Massachusetts Institute of Technology
Milton Klein
Vice-president, Electric Power Research Institute

Electrical Engineering: Its Societal Impact and Future Directions
June 12
Cornell University, Ithaca, New York
Speakers:
Hans Bethe
Professor of physics, emeritus, Cornell University
Lewis Branscomb
Vice-president and chief scientist, IBM Armonk
S. J. Buchsbaum
Executive vice-president, customer systems, AT&T Bell Laboratories
Alfred Kahn
Professor of economics, Cornell University

CELEBRATING A CENTENNIAL

Cornell Electrical Engineers to Convene at Symposia in Six Cities

Cornellians will be looking to the future as they observe the one hundredth anniversary of electrical engineering at the University in a series of symposia this spring. Reminiscences will share the agenda with discussions of major areas of activity and promise in the discipline today.

Beginning with the first symposium in Stanford on March 15, the series will culminate in a celebration in Ithaca on June 12 (just before alumni reunion weekend). In between, there will be symposia in East Windsor, New Jersey on April 1; in Newton, Massachusetts on April 10; in St. Louis on April 17; and in Washington, D.C. on April 25. The program in each city will also include a dinner with a featured speaker. More than a thousand alumni are expected to attend the various symposia.

According to Professor Lester F. Eastman '53, the general chairman of the centennial program, well-known figures including leaders in some of the major subfields of electrical engineering will speak at the symposia. They are listed in the summary opposite.

Faculty chairmen for the various symposia are Edward D. Wolf (*Microelectronics*), H. C. Torng (*Computers*), Toby Berger (*Communications*), Donald T. Farley '56 and Michael C. Kelley (*Atmospheric and Space Sciences*), Ravindra N. Sudan and Robert J. Thomas (*Energy for the Future*), and Herbert J. Carlin and Christopher Pottle (*Electrical Engineering: Its Societal Impact and Future Directions*).

The technical and local chairmen include Charles Sporck '51, F. Joseph Van Poppelen '49, and John Monroe '66, in Stanford; John M. Scanlon '65 and Roger Berman '70 in East Windsor; James L. Broadhead '57 and and Glenn Thoren '72 in Newton; Charles F. Knight '57, L. Keever Stringham '33, and Anatole Browde '48 in St. Louis; Donald M. Kerr '61 and Joseph Stregack '63 in Washington; and Dale R. Corson and John Belina '74 in Ithaca. Members of the Cornell Society of Engineers are involved; President John R. Boehringer '52 has designated the centennial as the society's major project this year.

Eastman is assisted in planning the centennial program by a large contingent of faculty and staff members and alumni. Mary F. Berens, director of engineering public affairs at the College, is coordinating the arrangements. Charles Yohn '50, director of engineering corporate relations, is helping to involve business and industry. Professor Simpson Linke is in charge of publicity, publications, and a special traveling exhibit.

Publications prepared in connection with the centennial include *Research in Electrical Engineering at Cornell*, which contains photographs and full-page descriptions of the research programs of faculty members. A limited number of copies is available.

With enthusiasm mounting, the centennial is sure to be a lively, substantive observance of great interest to practitioners in one of the leading technical fields of the times. This spring Cornell electrical engineers will enjoy the present pleasure of honoring their school's distinguished history and anticipating an exciting future for their profession.—*G. McC.*

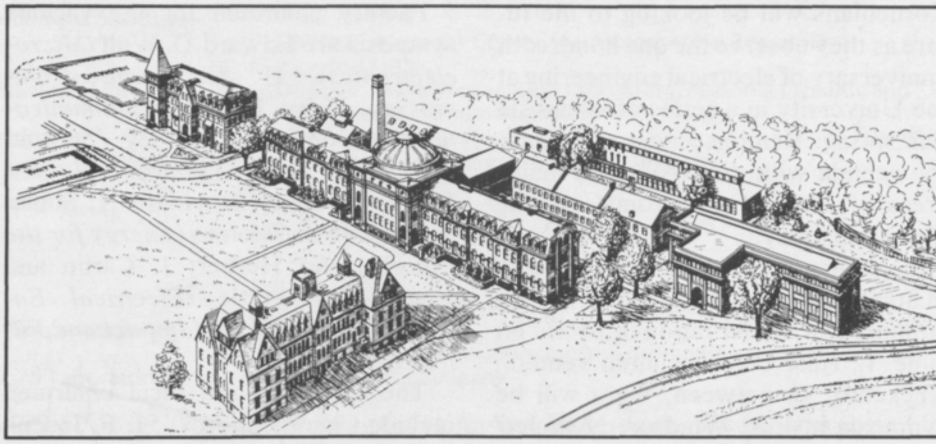
THE ELECTRIC CONNECTION

A Century of Electrical Engineering at Cornell

by Simpson Linke

In 1885 three Cornellians were among the nation's first few baccalaureate graduates in electrical engineering, and one received the first Ph. D. ever awarded in the new discipline. Since then, thousands of Cornell electrical engineers have participated in the remarkable development of the field, and this year many of them are joining the School of Electrical Engineering in celebrating its centennial.

Although the chief thrust of the nationwide series of centennial events is the current vitality of electrical en-



Right above: A sketch of the Cornell campus showing the early engineering buildings. Franklin Hall (Electrical Engineering) is at left. Next to it is Sibley Hall (Mechanical Engineering). Behind Sibley are two buildings used as mechanical laboratories. Rand Hall, housing a machine shop, a pattern shop, and an electrical laboratory, is at right. In the background, across University Avenue, are a highway laboratory, and a forge shop and foundry.

Below: A recent view of the same general area, which is now the Arts and Sciences Quadrangle.

The statue of Ezra Cornell, on the first campus quadrangle, shows him with his hand on a replica of the Morse telegraph instrument. (A photograph of the original instrument is on the outside cover.) Ezra Cornell supervised the construction of the first telegraph transmission lines and was associated with Morse in the Western Union Telegraph Company. The statue faces Goldwin Smith Hall on what is now the "Arts Quad."

gineering and its possibilities for the future, the view will be retrospective as well, honoring Cornell's distinguished history in electrical engineering and celebrating its past accomplishments.

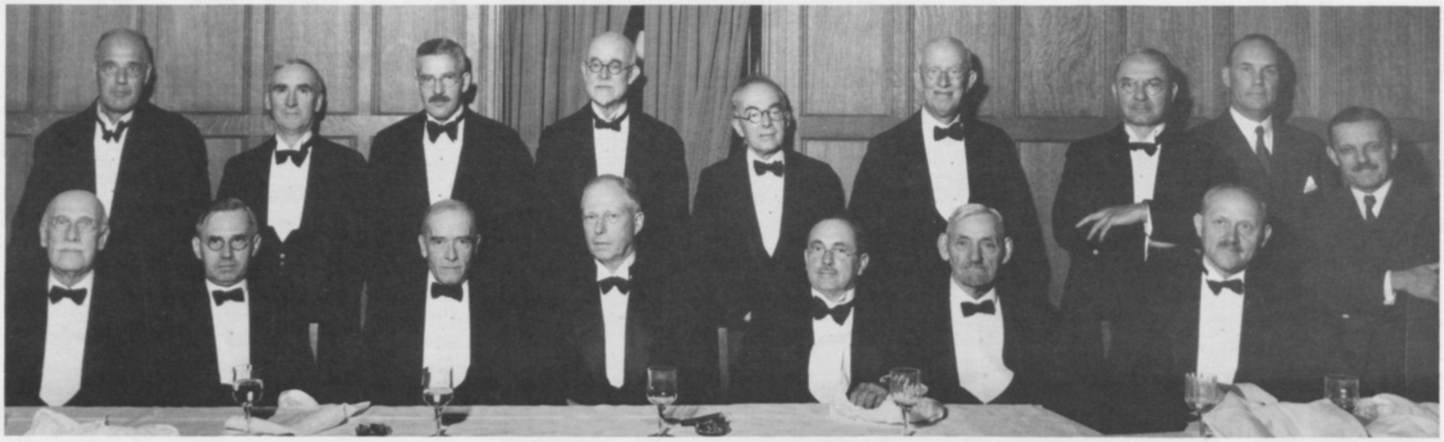
The brief historical survey given here is based partly on an article written by Donald F. Berth and the late Howard G. Smith and published in the 1976 summer issue of *Engineering: Cornell Quarterly*. (A limited number of copies are available and can be supplied on request.)

EZRA: THE FIRST CORNELL TO WORK WITH ELECTRICITY

Electrical engineering was not a subject of instruction when Cornell University opened in 1868, but it had a presence. The University's founder, Ezra Cornell, had developed and installed Samuel F. B. Morse's first telegraph line, along the right-of-way of the Baltimore and Ohio Railroad. In May of 1844, when the first dots and dashes were tapped out by Morse in Washington, D.C., and received by Albert Vail in Baltimore, it was Ezra Cornell's line that carried the historic message, "What hath God wrought." Cornell later supervised the construction of additional transmission lines, and he became a major stockholder in the Western Union Telegraph Company, formed in 1856. The capital to establish the University came largely from Ezra's Western Union earnings.

Instruction began at the new university eight years before Alexander Graham Bell formed the first telephone company, and commercial electric power was just beginning to appear when electrical engineering was introduced as a full course of study in 1883. Cornell was one of the two universities (the Massachusetts Institute of Technology was the other) that responded quickly to the imminent need for engineers prepared to develop the technology.

There could hardly have been more fertile ground for the germination and flowering of the new discipline. Ezra Cornell, with his background as a practitioner in the early application of electricity, established the University's motto—which still appears on let-



Well-known figures at Cornell attended a 1931 banquet meeting at which George S. Moler was honored. The Cornell Society of Engineers presented an illuminated, leather-bound certificate to Moler, "who with Professor William A. Anthony built at Cornell University in 1875 the first dynamo in the Western Hemisphere." The citation continued, "This marked the beginning of the era of electric light and power which has contributed inestimably to the progress of civilization." The occasion was the sixtieth anniversary of the founding of engineering at Cornell and the centenary of the discovery of electromagnetic induction.

The photograph was loaned by George F. Critchlow, one of Moler's grandsons, who supplied some identification of those present. Moler is seated second from the right. Standing, left to right, are Paul M. Lincoln, director of the School of Electrical Engineering; Dexter S. Kimball, dean of the College of Engineering; Walter L. Conwell, associate dean; E. L. Nichols, professor of electrical engineering until 1919; Ernest G. Merritt, professor of physics and electrical engineering; an unidentified dignitary; Herman Diederichs, director of the Sibley School of Mechanical Engineering (later dean of the College); James Lynah '05 (who became Cornell's director of athletics in 1935); and Walter B. Carver, professor of mathematics. Seated, left to right, are Albert W. Smith, director of Sibley College from 1904 to 1921; Albert R. Mann, the University's first provost (earlier dean of the College of Agriculture); Livingston Farrand, president of the University; Bancroft Gherardi, trustee; C. F. Hirschfeld, professor of electrical engineering; Moler; and Ellis L. Phillips '95 (later the donor of Phillips Hall).

An additional photograph, showing the dynamo, is on page 45.

terheads and official documents—when he declared at the inaugural ceremony that "I would found an institution where any person can find instruction in any study." The first president, Andrew Dixon White, also had a strong interest in technical education. "...as early as 1857," he wrote in his autobiography, "I began to realize that we were at the beginning of a new epoch, as regarded instruction in the sciences...both pure and applied. When I [later] took my seat in the Senate of the State of New York, I exerted myself to the full extent of my power, preaching, early and late, the necessity of more and higher technical education."

AN INSTITUTION READY FOR A NEW DISCIPLINE

Engineering was an important part of the University curriculum from the beginning. A College of Mathematics and Engineering (including civil engineering) and a College of Mechanic Arts (forerunner of the present Sibley School of Mechanical and Aerospace Engineering) were among the initial academic units. In the early years, electrical studies were included in the physics program, but in 1883 a special curriculum leading to a baccalaureate degree in electrical engineering was established. By 1885 it was incorporated into Sibley College of the Mechanic Arts, as it was then named; this organization was a logical development, since early electrical technology was electromechanical.

The moving force behind the establishment of the electrical engineering curriculum was the University's first professor of physics and industrial mechanics, William A. Anthony. One of Anthony's earliest projects was the construction, in the Sibley Hall shops, of the first dynamo in the United States. George S. Moler, an 1874 mechanic arts graduate, was Anthony's chief assistant in building the machine; another helper was Elmer Sperry, who later organized one of the nation's large industrial complexes. The historic Cornell machine, copied from the French Gramme dynamo, was shown at the national Centennial Exhibition held in Philadelphia in 1876. After the exhibition closed, the dynamo was returned to Cornell, where it powered the nation's first outdoor electrical lighting system: two carbon-arc lights on the campus.

In organizing the course of instruction in electrical technology, Anthony had the enthusiastic backing of President White. In fact, a letter written by White in 1893 included the remark, "It was I who, as Professor Anthony will testify, suggested the establishment at Cornell of the first Department of Electrical Engineering ever erected in the United States, indeed, ever created anywhere, as far as I know...." Anthony presented a detailed plan for the program to the executive committee of the University trustees on March 22, 1883, and four days later the committee authorized the faculty to announce "a course of study in electrical engineering, leading to a degree, provided such a course occasions no additional expense." The responsibility for any "additional expense" appears to have been personally assumed by President White.

THE FIRST PROGRAM IN ELECTRICAL ENGINEERING

Facilities for the new program were provided in Franklin Hall, the new Physical Laboratory named "in honor of the first American electrician." The announcement of the course of study, prepared by President White himself, appeared in a special insert in the 1883-84 *University Register*. Since they had already taken many of the required courses, those first three graduates in electrical engineering were able to complete the course in two years; in 1885 the first baccalaureate degrees in electrical engineering were awarded.

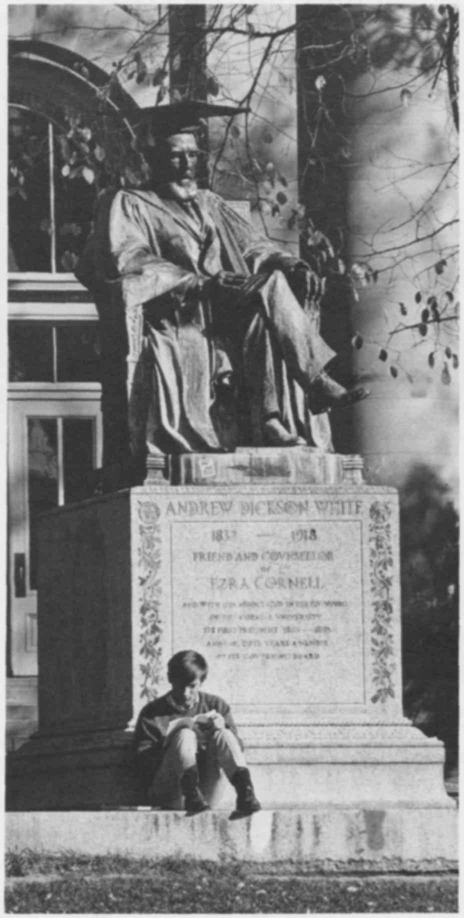
The curriculum for the freshman year consisted of mathematics (geometry, algebra, and trigonometry), drawing (freehand, instrumental, and text), French or German, and rhetoric. The students also had military drill and some lectures in hygiene.

In the sophomore year there were classes in calculus; experimental mechanics and heat; electricity and magnetism; acoustics and optics; chemistry; and shop. Instruction was continued in French or German, geometry, and military drill.

The junior year included classes in calculus; physics with laboratory work in mechanics, measurements, electricity, general experiments, and acoustics and optics; chemistry with laboratory; mechanics of engineering; mechanical drawing; and shop.

Physics courses in the senior year covered electrical technology: photometry and electric lamps; telegraph instruments, lines, and cables; the dynamo and electric motors; and instrument testing. Other courses were

"There could hardly have been more fertile ground for the germination and flowering of the new discipline."



A statue of the University's first president, Andrew Dixon White, stands in front of Goldwin Smith Hall. The inscription reads, "Friend and counsellor of Ezra Cornell and with him associated in the founding of the Cornell University. Its first president 1865-1885 . . ." White promoted the development of technical education and was supportive of the introduction at Cornell of the nation's first electrical engineering curriculum.

in the mechanics of engineering, the steam engine, hydraulics, mechanical drawing, and military science. In addition, a thesis was required.

1885: LANDMARK YEAR FOR E.E. AT CORNELL

The place of electrical engineering in the University organization shifted in 1885 from its affiliation with both physics and mechanics (a combination stemming from Anthony's dual appointment) to mechanical engineering when Robert Henry Thurston became director of the again renamed Sibley College of Mechanical Engineering and the Mechanic Arts. An electrical engineering department was set up within Sibley College, although it continued to be housed with physics in Franklin Hall until 1904, when Rockefeller Hall was built as the new physics facility.

The year 1885 emerges as a landmark year. Electrical engineering was established as a separate department, and the first group of students was graduated. It was fitting that those first electrical engineering degrees—three bachelor's and the single doctorate—were conferred by President White, who had played such a large role in the early development of electrical engineering at Cornell. The 1885 graduation ceremony was the last conducted by White, who had just announced his resignation after twenty years as president of the University.

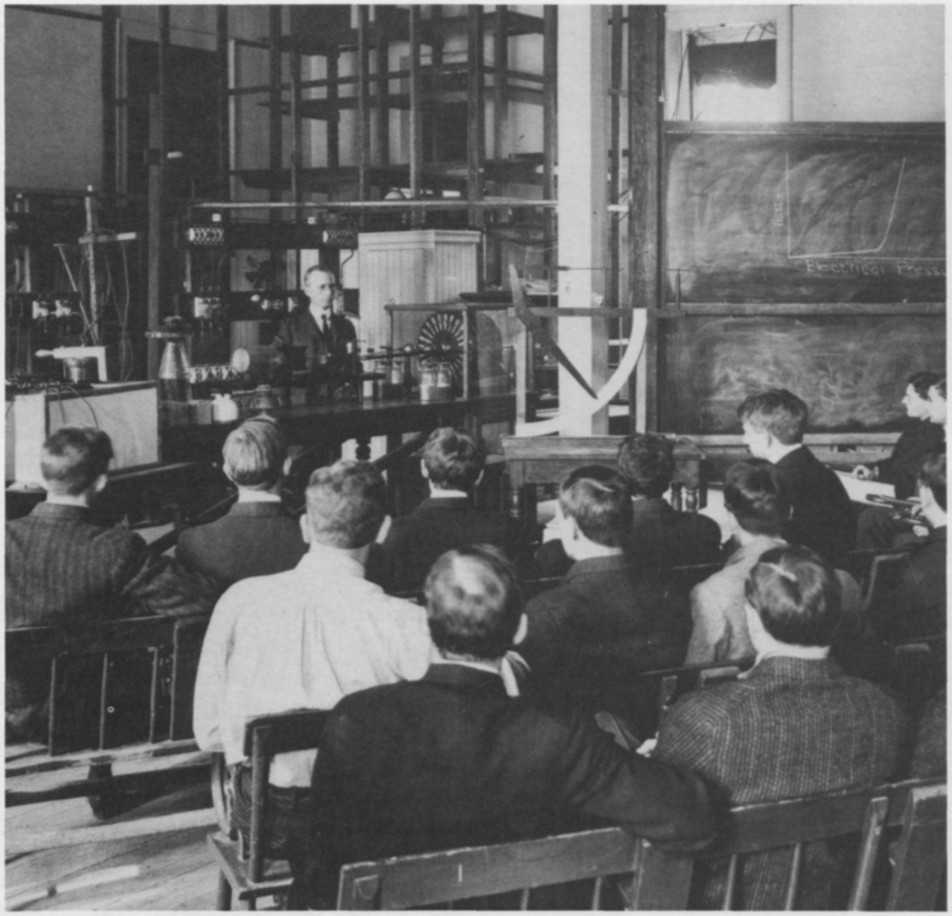
Incidentally, that first Ph. D., James G. White, may also have been the first electrical engineering member of Sigma Xi, the honorary scientific research society that was founded at Cornell in 1886 by several engineering students and has become a world-wide organization of more than 120,000 members.

Cornell University soon became recognized for its prominence in electrical engineering education. An article in *The Electrical World* in 1890, for example, credited Cornell with having the nation's leading program in the new discipline.

RYAN AS STUDENT AND ONE-MAN FACULTY

When Anthony left Cornell in 1887 to accept a position with the Mather Electric Company in Manchester, Connecticut, his replacement was one of his students, Harris J. Ryan. Ryan had entered the first class in 1883 and was graduated in 1887. After working for a year at the Western Electric Company (with Cornellians James G. White, that first Ph. D., and Dugald C. Jackson, who later headed electrical engineering at MIT), Ryan returned to Cornell in 1888, first in the physics department and then in the Sibley College. For many years he taught practically all the applied courses in electrical engineering.

While he was still a student, Ryan had served as Anthony's assistant in work on electrical standards; one of the notable achievements was the building of a large tangent galvanometer. As a faculty member, Ryan worked closely with colleagues in the physics department—Edward Nichols and Ryan's former classmates Ernest Merritt and Frederick Bedell. For some years, therefore, the tie between physics and electrical engineering continued productively.



Harris J. Ryan, shown in his classroom, was essentially a one-man electrical engineering faculty before the turn of the century. In the safety cage behind him is a high-voltage transformer, now in the Phillips Hall collection.

Ryan's first studies as a faculty member centered on alternating current. An early accomplishment was the adaptation of the cathode ray tube for use as a laboratory tool; in 1906, for example, Ryan obtained a patent covering magnetic deflection of the beam. Operating without inertia, the new instrumentation was capable of measuring rapid and complex periodic electrical phenomena. Power transmission became his chief speciality, however. He designed and built an early high-voltage (10 kV) transformer; it is displayed occasionally in Phillips Hall on state occasions, but, sadly, is no longer in safe operating condition.

Under Ryan, the numbers of electrical engineering graduates rose steadily. In 1889 there were eighteen baccalaureate graduates; in 1897, after ten years of Ryan's leadership, there were almost seventy. And for many years, Cornell conferred the largest number of advanced degrees in electrical engineering in the nation. By the time he left Cornell in 1905 to become head of the Department of Electrical Engineering at Stanford University, Ryan had prepared nearly one thousand Cornellians as electrical engineers.

THE YEARS BEFORE WORLD WAR II

The same year that Ryan left Cornell, Vladimir Karapetoff joined the faculty, and for thirty-five years was a leading figure in electrical engineering at Cornell. He also became known internationally for his contributions to early electrical engineering theory and analysis, as presented in several textbooks and many technical articles.

Something of the flavor of electrical engineering studies of the time is suggested by the following excerpt from Karapetoff's *Electrical Laboratory Notes,* published in 1906: "In coming to the laboratory, bring with you a slide rule, an inch rule or tape, a speed counter, a screw driver and a pair of plyers [sic]. This will save you time and trouble of looking for them or borrowing them. Do not forget to have a pocket knife for skimming off wire; a bicycle wrench is also sometimes very handy to have."

Right: In the 1930s one of the electrical engineering professors was Burdette K. Northrup, shown with an early gas-discharge rectifier.

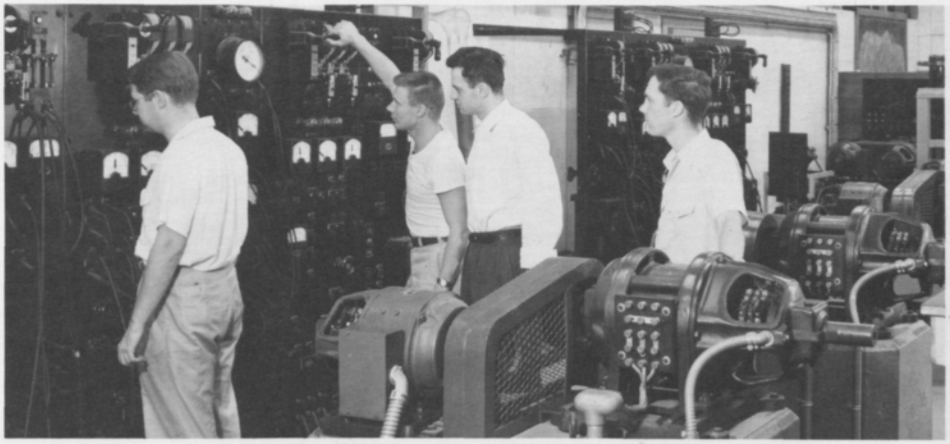
Below: Henry H. Norris became head of the department in 1905. Writing on the blackboard indicates that the subject in this class was "Design of Street R'y Motors."

Administrative leadership of the department passed from Ryan to Henry H. Norris, a member of the Sibley College faculty. He remained until 1914, when he resigned to become editor of the major trade journal *Electrical World*. Karapetoff served briefly as department head, and then Alexander Gray came from McGill University to take over the leadership. Five years later, a few months after the establishment in 1921 of a separate school for electrical engineering, Gray died at the age of forty.

The School of Electrical Engineering was established as part of the newly created College of Engineering, which incorporated schools in three engineering disciplines—civil, mechanical, and electrical. Sibley College became the Sibley School of Mechanical Engineering, without its electrical engineering adjunct, and for the first time, students who majored in electrical engineering received degrees in that discipline rather than in mechanical engineering. The creation of a single engineering college, a development that had already occurred at most major institutions, helped revitalize an engineering program that had been experiencing a decline. Dexter S. Kimball, a Cornell professor who had pioneered in the development of industrial engineering, was named the first dean of the College of Engineering.

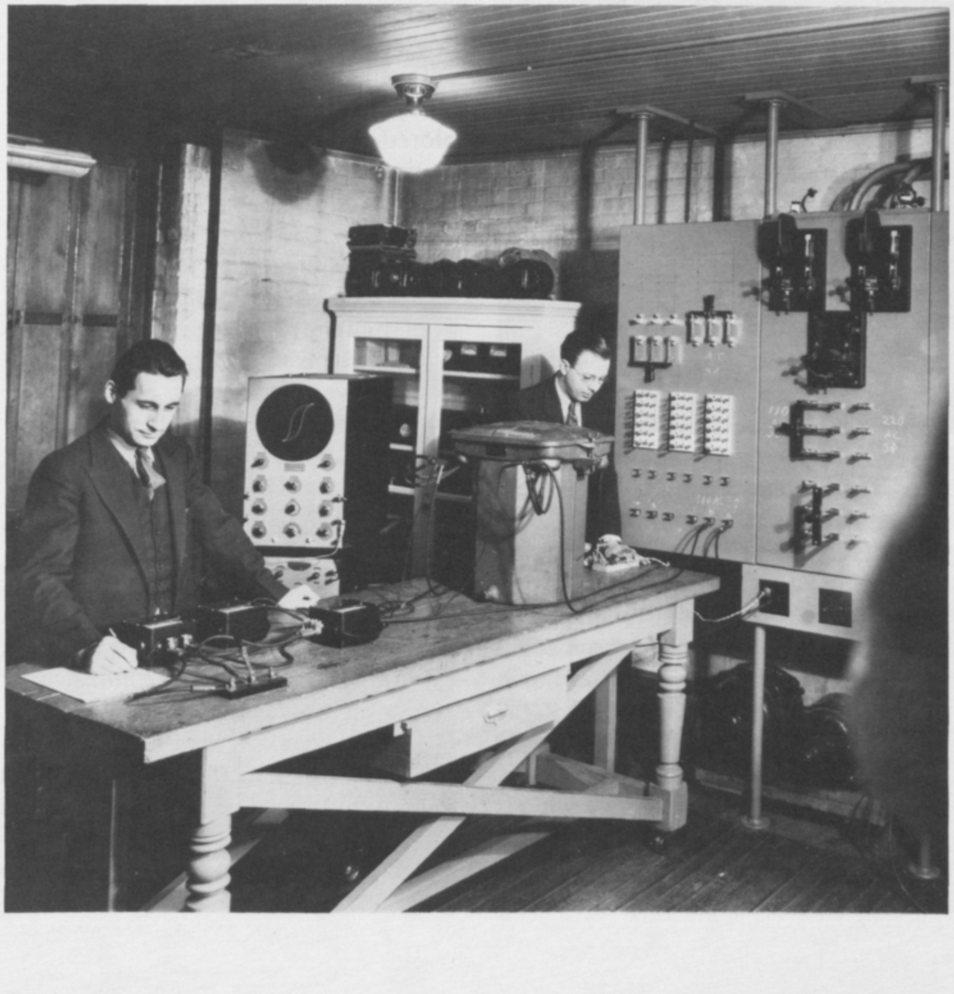
One of the first necessities was finding a new head for electrical engineering. Shortly after Gray's death, Kimball announced the appointment of Paul M. Lincoln as the first director of the School of Electrical Engineering. Lincoln (brother of the founder of the Lincoln Electric Company in Cleveland) had extensive industrial experience, including seven years as superintendent of the Niagara Falls Power Company plant, and he had served as president of the American Institute of Electrical Engineers. As director, Lincoln increased the faculty from eight members to a level of about twenty, despite the financial difficulties accompanying the great national depression.

Leadership at the College level passed to Herman Diederichs, who became dean in 1936, and then to S. C. Hollister, dean from 1937 to 1959. At the School of Electrical Engineering, the director who succeeded Lincoln when he retired in 1938 was William A. Lewis, a young electrical engineer who had been educated at the California Institute of Technology and employed at Westinghouse. Lewis was able to foster new vigor at the School, despite the increasing obsolescence of Franklin Hall. A high-voltage laboratory was built and became the center of an active research program in electric power transmission.



Left: The Diesel School at Cornell was part of the navy's World War II training program. Here electrical engineering students in the program perform a d.c. machine experiment. (People who were at the school at the time recall that the equipment in the laboratory was painted navy blue.)

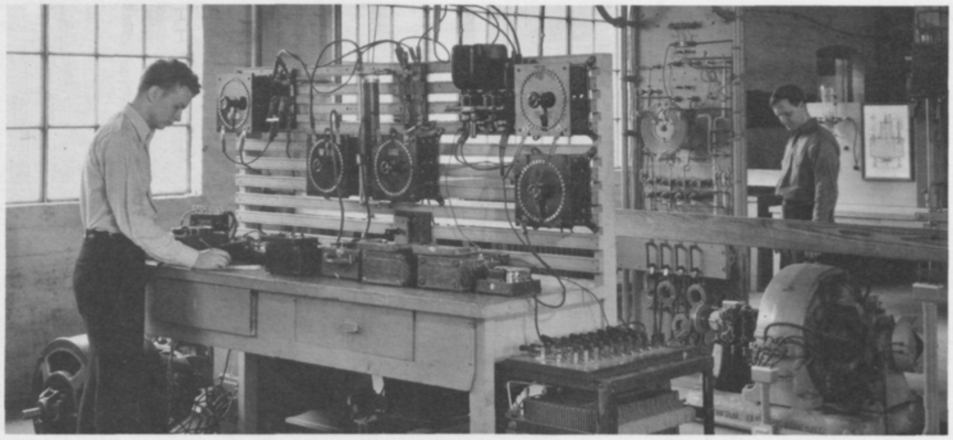
Below: During the war years, Everett M. Strong chaired a faculty committee that administered the electrical engineering school. He is shown here (at left) in his Franklin Hall laboratory with Lawrence Spencer, an instructor. They are performing a transformer experiment using an early oscilloscope.



THE WAR PERIOD AND ITS AFTERMATH

World War II transformed the entire Cornell engineering program. New courses in emerging technologies were introduced, mostly as a result of programs sponsored by the military; these included special programs set up by the navy in diesel and steam engineering and by the Army Signal Corps in radar. Electrical engineering was heavily involved; the Diesel School, for example, provided instruction in the operation of a.c. synchronous and induction machines. A large contingent of naval V-12 students earned degrees in electrical engineering in three years by attending classes year-round.

Changes also occurred in the administration of the School of Electrical Engineering. Lewis resigned as director in order to become dean of the graduate school at the Illinois Institute of Technology, and for the remainder of the war period the School was administered by a faculty committee headed by Everett M. Strong. (An elected faculty advisory committee remained part of the school organiza-



Rand Hall, where this machinery experiment is in progress, was one of the buildings used for electrical engineering instruction before Phillips Hall was built.

tion from 1946 on.) A new director, Charles R. Burrows from Bell Telephone Laboratories, was appointed in the fall of 1945.

A significant factor in the postwar period was the so-called G.I. Bill, which provided support for thousands of veterans who wished to pursue a college education. This created a severe personnel crisis in the School of Electrical Engineering: in 1946 there was a sudden influx of veterans into the program, and in addition, there were heavy demands for "service courses" for students enrolled in chemical, civil, and mechanical engineering. The immediate need for teachers was met by appointing a dozen new graduate students as full-time instructors. (Seven members of that group—Nelson H. Bryant, Clyde Ingalls, Simpson Linke, Henry McGaughan, Benjamin Nichols, Joseph L. Rosson, and Norman M. Vrana—remained at Cornell to become full professors; five are still fully active in the School.)

By 1950 the wave of veterans had abated and the School began to assess its future course. An obvious need was to expand instruction in new areas of science and technology; twenty new members were added during Burrows's twelve-year directorship. The College was also faced with the necessity to incorporate more material into the undergraduate curricula, and in an effort to accomplish this without sacrificing educational breadth, instituted a five-year professional program for all undergraduates.

A related issue in the School of Electrical Engineering was whether the research program should be greatly expanded. New faculty members tended to be critical of the lack of extensive research in the School, and complained that the faculty was not competing for the greatly increased federal funding that had become available after the war. On the other hand, several of the older members of the faculty, while recognizing the great personal value of individual investigations, were opposed to large-scale research projects; they maintained that the principal function of the School should be the instruction of undergraduates and a limited number of graduate students. Others, who were enthusiastic about expanding graduate study and associated research, deplored the great lack of facilities and equipment that was the legacy of the depression and the war years. In truth, the School's activities were being conducted in portions of four buildings—Franklin Hall, Franklin Annex, Rand Hall, and the Old Heating Plant on the south campus near the present Bard Hall. It was clear that a new building was a critical necessity, and Director Burrows appointed a planning committee to look into the problem.

THE INSTRUCTIONAL AND RESEARCH INITIATIVES

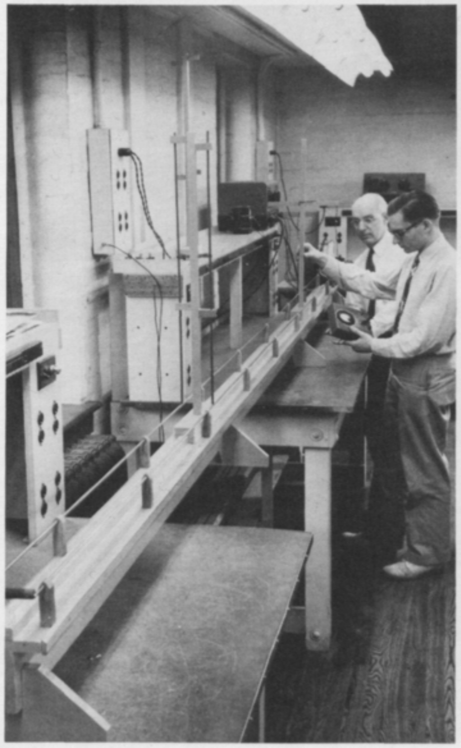
In this interim postwar period, a number of outstanding undergraduate programs had been well established by senior members of the faculty.

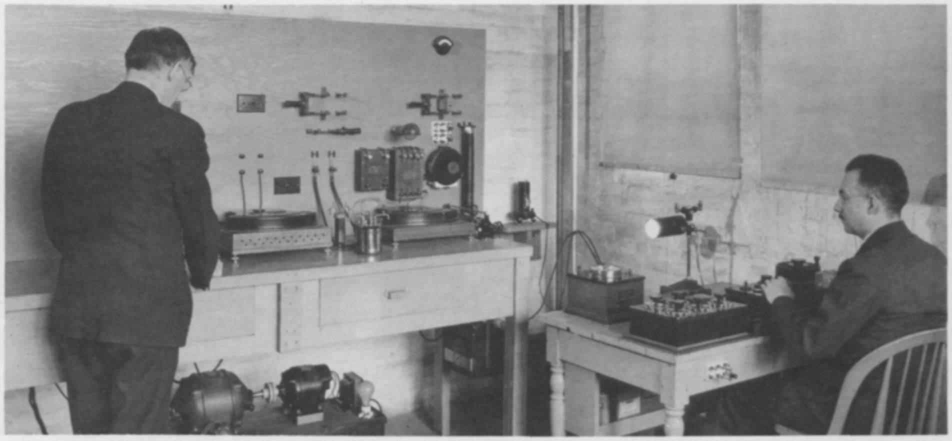
L. A. Burckmyer and Robert E. Osborn perfected the famous "Rand Labs" (in Rand Hall) that emphasized clear thinking and precise measurements in experiments related to magnetic circuits and electric ma-

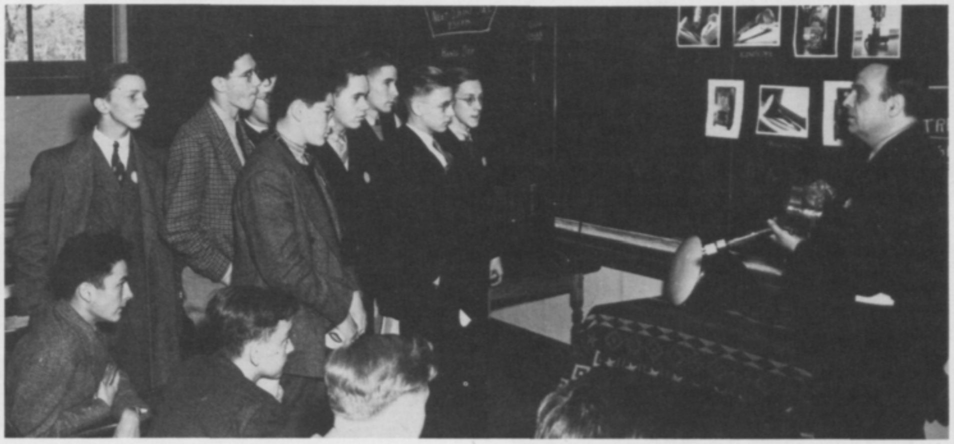
Below: During the postwar period, True McLean taught and conducted research in radio engineering. The photograph shows him (at left) in his Franklin Hall laboratory, carrying out an early radiofrequency-transmission-line experiment.

Right: The standards laboratory in the basement of Franklin Hall provided the valuable service of accurately calibrating electrical instruments. Robert Chamberlain (at left) and L. A. Burckmyer (at right) were two of the three professors who established the laboratory.

Right below: In his Franklin Hall classroom, Professor William C. Ballard is demonstrating the Zworykin Iconoscope, an early electronic television "camera." An early receiver tube is on the table.







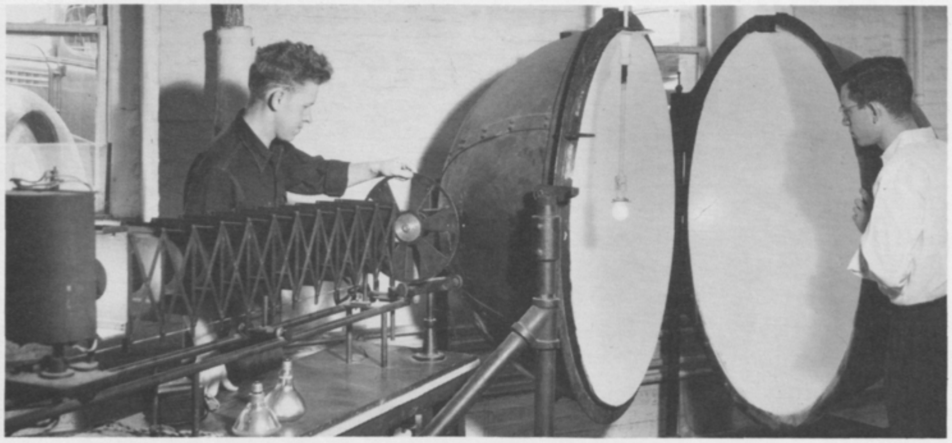
chinery. (Scores of electrical engineering alumni remember these courses as being very demanding and even painful. After entering their professional careers, however, many of these same alumni reported their appreciation of the value of these rigorous exercises.)

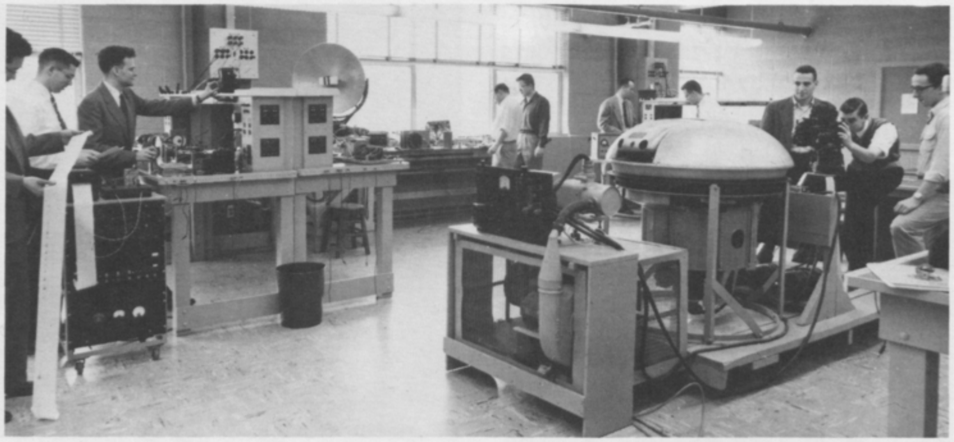
A. Berry Credle and Howard G. Smith offered correspondingly thorough courses in communications theory and transmission lines and filters, while True McLean taught courses in radio engineering and associated electronic circuitry that were particularly effective because of his extensive practical engineering background and developmental experience in these fields. Robert Chamberlain, Burckmyer, and McLean also developed and maintained a unique standards laboratory in the School that for many years served the entire University and many area industries as a highly accurate calibration facility.

Wilbur E. Meserve pioneered courses in the new field of "servomechanisms" that set the stage for the advanced feedback-control studies

Right: This spherical photometer in the illumination laboratory in Franklin Hall was used to measure total light flux, in lumens, by comparison with a standard source (at left in the photograph). Professors Everett M. Strong and Caspar L. Cottrell were the School's specialists in illumination.

Right below: By the mid-1950s a laboratory for work in servomechanisms (employing feedback control principles) had been established in the new Phillips Hall. Much of the equipment, including radar apparatus, was war-surplus material.





and research of today. William C. Ballard devised a vacuum-tube electronics laboratory that provided valuable research facilities for graduate students of the day and paved the way for the physical-electronics research of the 1950s and 1960s that eventually led to the extensive microelectronics investigations of today.

Everett M. Strong, a well remembered enthusiastic teacher of electrical engineering fundamentals, joined with Caspar L. Cottrell in offering courses and conducting investigations in illumination theory and practice. B. K. Northrup and Walter W. Cotner offered laboratory courses in power-electronics systems and Michel G. Malti was widely known for his courses in advanced circuit analysis and transient behavior. Paul D. Ankrum began development of new courses in semiconductor electronics that were to remain popular throughout his career at Cornell.

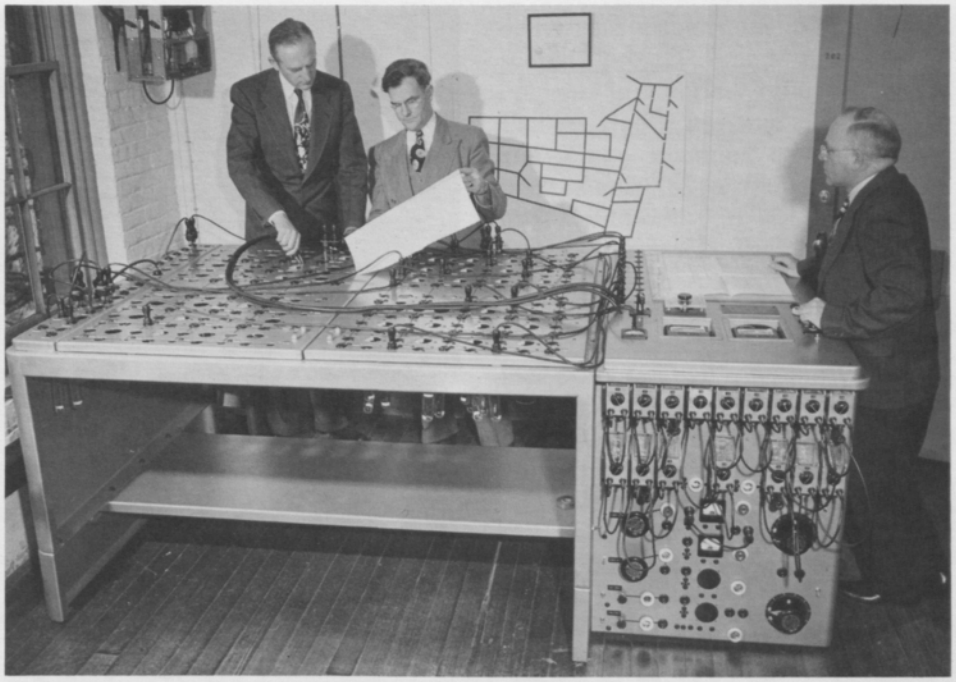
It is of interest to note that Ballard, McLean, and Northrup were responsible for the establishment of the Cornell radio station WHCU, which is still owned and operated by the University. At the end of World War I, Ballard and Northrup had licensed an experimental radio station in Franklin Hall, and in 1923 they obtained a standard broadcast license for Ithaca's first station, then called WEAI. Upon Northrup's resignation in the same year, McLean began working with the station, and continued the association throughout his career at Cornell.

Director Burrows, recognizing the inherent strengths of the educational program in the School, was determined to establish an equally strong research effort. In the first years of his administration he began a vigorous recruiting campaign that brought Henry Booker, Walter R. Jones, Malcolm S. McIlroy, Joseph G. Tarboux, and Stanley W. Zimmerman to the School as full professors.

Booker, a widely known authority on electromagnetic theory and radar, offered advanced graduate courses in these specialties. Also, with other newly recruited faculty members, he began a substantial research effort in the new field of radio astronomy—a study of solar radiation carried out with relatively elaborate facilities installed at Tompkins County Airport. These early investigations eventually brought Cornell international recognition as a center for work in radiophysics and space research, and led directly to the establishment of the Arecibo radar-radio telescope, the largest in the world. (The Arecibo story is recounted below.)

Jones brought his extensive industrial background and war-effort expertise to bear on vacuum-tube research, and in a short time had established a substantial research program in vacuum-tube failure analysis that took advantage of the availability of Ballard's tube laboratory. This program contributed in a major way to Cornell's developing eminence in physical electronics.

McIlroy, who had invented a novel pipeline analyzer (an electrical analog for the study of commercial water- and gas-supply networks), was an early investigator in the application of analog and digital computers to com-



Above: A nonlinear system analyzer for studying pipeline networks was invented by Malcolm S. McIlroy (at left). He and his colleagues Jack Tarboux (center) and Walter R. Jones (at right) were key researchers at the School in the years following World War II.

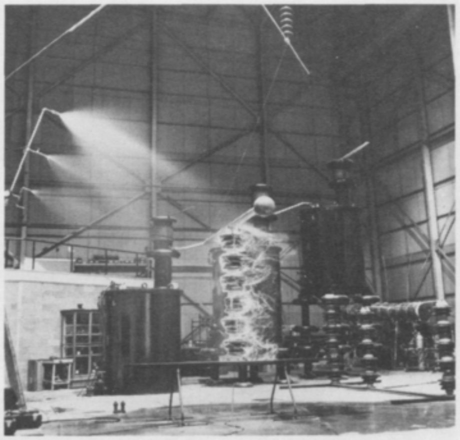
Left: Voluminous solar astronomical data were collected at a facility at the Tompkins County Airport in the early 1950s. Lorne Doherty (at right), was a Ph.D. student of Henry Booker; S. Michel Colbert (at left) later became a staff member of Cornell's Center for Radiophysics and Space Research.

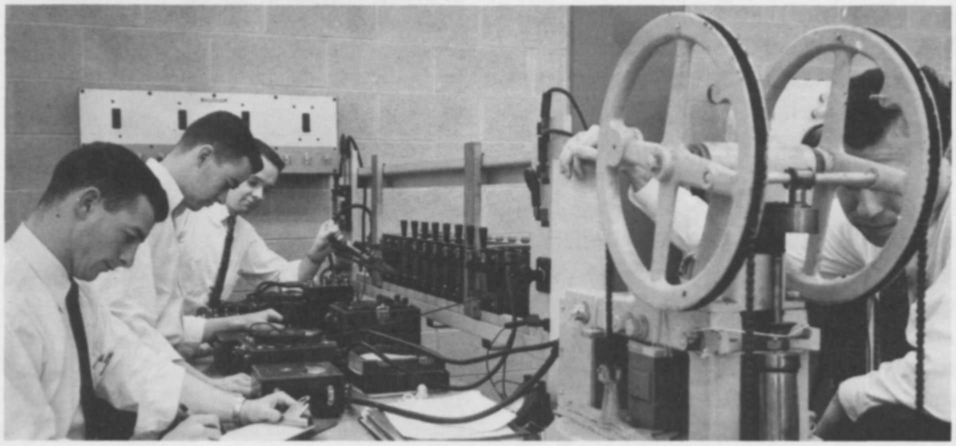
Right: At the airport facility, this polar-mounted antenna was used to track the sun. At left is Charles Seeger, an assistant professor (brother of the folk singer Pete Seeger); at right is Professor William E. Gordon.

Right: In the original high-voltage laboratory, before the fire, a 750-kV a.c. transformer test set creates a discharge across a string of insulators (at center). Jets of water were used to simulate misting.

Below: The vacuum-tube design laboratory was moved to Phillips Hall in 1955. Lester F. Eastman, then an assistant professor, is second from the right.

Bottom: A constant-current transformer experiment in the power laboratory in Phillips Hall was performed with equipment similar to that used in street-lighting systems.





plex electrical networks. He was an ardent supporter of academic research in the School until his untimely death in 1955.

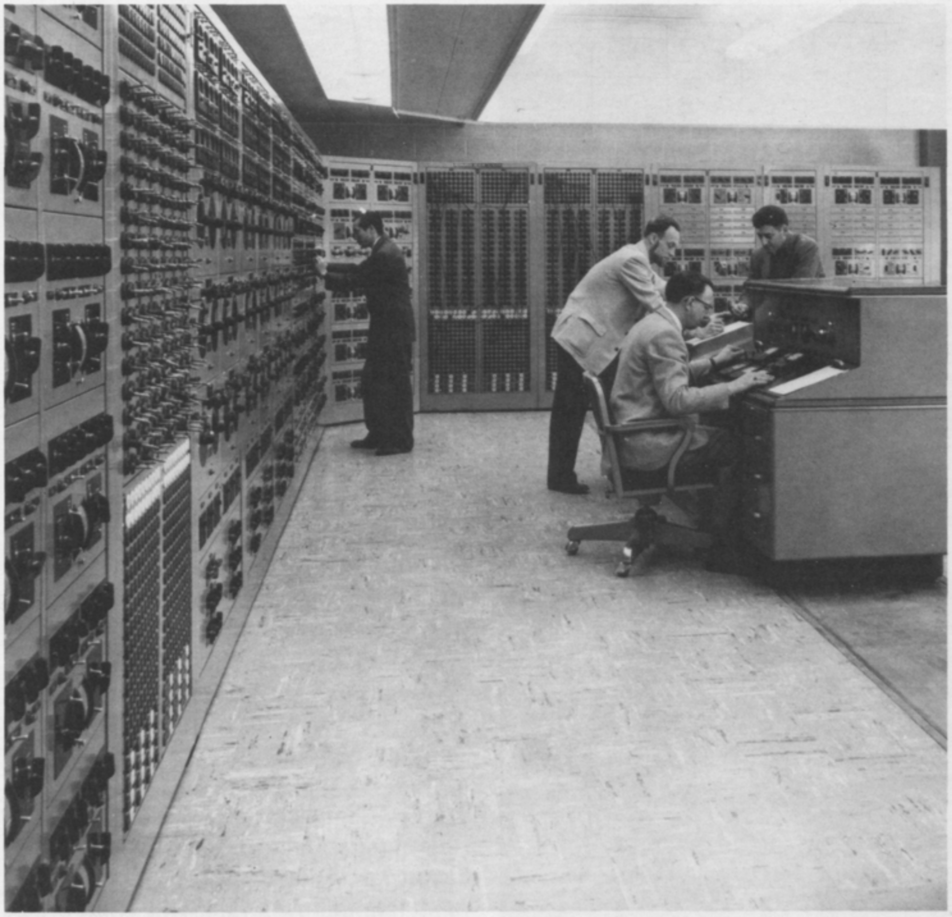
Tarboux, a recognized authority on power-system analysis, was given the task of restoring Cornell's earlier dominance in that field and encouraging advanced research in the projected new problems of electric-power generation and transmission.

Zimmerman, a well-known industrial specialist in extra-high-voltage investigations, assumed responsibility for developing a teaching and research program for the Mitchell Street High Voltage Laboratory. This facility contained extra-high-voltage transformers and a 3-million-volt surge generator. (Unfortunately, the laboratory was lost in an enormous fire in 1947, and although it was rebuilt some years later, it was not again used for standard high-voltage studies; eventually it became one of the principal facilities of the Laboratory of Plasma Studies.)

A NEW BUILDING FOR AN ACTIVE SCHOOL

A new building for the School of Electrical Engineering became a reality in February, 1955, when Phillips Hall was dedicated. Funds had been provided by the Ellis L. Phillips Foundation, and it was named in honor of that 1895 graduate, founder of the Long Island Lighting Company. The new building provided 60,000 square feet of classroom, laboratory, and office space. Only 10,000 square feet were reserved for research; this was considered to be adequate for a projected maximum of fifty graduate students.

For some years the faculty was very



An a.c. network calculator was used in the mid-1950s for cooperative studies with electric utilities.

comfortable with the newly acquired space and the convenience of a central facility for the majority of the activities of the School. The vacuum-tube laboratory and the associated tube-failure analysis project were more than adequately housed, a large electric-power-network analyzer was operative in a specially designed room, an elaborate illumination laboratory was in full use, and a modern laboratory distribution network brought a variety of electric services to all the laboratories in the building. A central machine shop and several smaller electronics shops at various locations in the building allowed flexible and efficient operations and encouraged innovation and expansion. As might be expected, though, this state of euphoria did not last very long. Encroachments on the available space accompanied increases in the number of undergraduate and graduate students, the establishment of new research projects, and new developments in a variety of areas. Today Phillips Hall is bursting at the seams, and a new planning committee has been established to study designs for a major addition.

ACHIEVING A MAJOR RESEARCH BREAKTHROUGH

In the spring of 1958 a new research idea proposed by Professor William E. Gordon opened the way to a significant development, the first of a number of milestones reached over the past twenty-five years by the School.

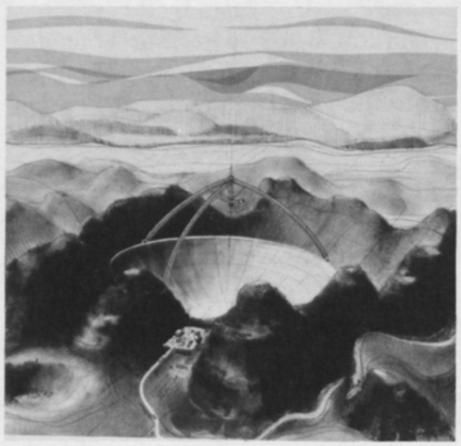
Gordon, who had become a member of the faculty soon after earning his Ph.D. under Henry Booker in 1953, was interested in the possibility of making measurements of incoherent backscatter from electrons in the ionosphere as a means of studying ionospheric characteristics. One evening during that momentous spring, he made some "back-of-the-envelope" calculations that suggested that such measurements could, indeed, be performed if one had a reflector dish that was 1,000 feet in diameter and had a smooth surface with a spherical curvature accurate to within one inch. Over the next few days, excited consultations with colleagues in electrical engineering and civil engineering resulted in confirmation that such a structure could be built.

Further research during the summer and a preliminary experiment conducted in October by Ken Bowles, another of Booker's former graduate students, showed that radar echoes of incoherent electron backscatter could be obtained through the use of state-

Below: This sketch shows an early impression of the radio-radar facility that later was built in Arecibo, Puerto Rico. This antenna support system was not the one actually used.

Right: The Arecibo facility actually built provided the world's largest radio-radar telescope.

Far right: For many years radio astronomers from the School of Electrical Engineering have also used Cornell's radar facility at Jicamarca in Peru, almost on the magnetic equator. The antenna consists of a grid of thousands of dipole antennas.



of-the-art radar. The idea led as a matter of course to a way of receiving radar echoes from the planets of the solar system, and of obtaining other astronomical information.

In consultation with Cornell colleagues in electrical and civil engineering, Gordon worked out the basic specifications for the structure and geographical location of such a huge facility. Eventually the necessary funding was obtained and Gordon supervised the design and construction. The facility was completed in 1963 and Gordon became the first director of the observatory. (It is now the National Astronomy and Ionosphere Center, operated by Cornell under contract to the National Science Foundation; the current director is Tor Hagfors, professor of astronomy and of electrical engineering.)

NEW PRIORITIES, PROGRAMS, AND CHALLENGES

In 1957 Director Burrows resigned—primarily because his eyesight was failing—and William H. Erickson served as acting director for the next two years until Henry Booker was appointed director in 1959. The faculty had been augmented by the arrival of G. Conrad Dalman in 1956 and Lester F. Eastman the following year.

Beginning in the 1960s, significant changes occurred in the School's attitudes toward education and research. Under the leadership of Booker, and the influence of younger members of the faculty, a novel modification was introduced in the electrical engineering curriculum. In effect, the School was divided into two major components, *Electrophysics* and *Systems*. Required junior courses and laboratories were drawn from both disciplines, but seniors and graduate students had the option of confining their studies to one of the two areas.

In spite of early fears that this dichotomy would split the School in two, the transition to the new program was smooth, and much of this educational structure remains in place today. Booker recruited ten new faculty members whose areas of interest were equally divided between the two main stems. Eight of these appointees—Ralph Bolgiano, Myunghwan Kim, Paul R. McIsaac, Christopher Pottle, Ravindra N. Sudan, James S. Thorp, H. C. Torng, and George J. Wolga—remain as full professors in the School.

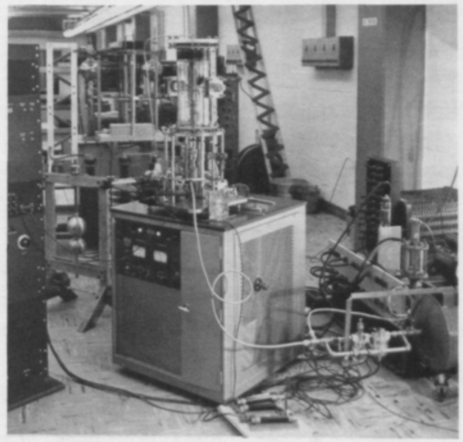
In 1961 a basic two-year curriculum for all undergraduates in the College was introduced: Freshmen no longer entered directly into a specialty field, but deferred this choice until the junior year. In 1965 the five-year baccalaureate program instituted after World War II was revised to a four-year B.S. degree program, with an optional fifth year leading to a professional master's degree. The M.Eng. (Electrical) option developed into a strong program, and today is valued both for the education of practitioners and as preparation for further study in the doctoral program.

In research, Booker encouraged the younger faculty members to submit proposals to various funding agencies in order to obtain support for graduate students and to further their own advancement in new fields of electrical engineering. (The ensuing flood of proposals prompted a National Science Foundation program manager to make a special visit to the School to find out what was going on—why a source that had previously submitted perhaps one request for funding in the entire history of the agency was suddenly producing a deluge.) The resulting research activities, during Booker's and succeeding administrations, included the following:

- The rebuilt Mitchell Street Laboratory was converted into a facility for energy research. It served as the staging area for a three-year project, under the direction of Joseph L. Rosson and Robert E. Osborn, that involved the testing of extra-high-voltage underground power cables and associated dielectric research.
- Two research projects in high-voltage vacuum circuit breakers and arc physics were started by Simpson Linke and Ravindra N. Sudan. Begun in Phillips Hall, the experiments were moved to the Mitchell Street facility.
- The earlier vacuum-tube reliability testing project was replaced by a new research program in physical electronics and microwave semiconductors under the direction of G. Conrad Dalman and Lester F. Eastman.
- Early investigations in laser and optical systems were initiated by George J. Wolga.
- A vigorous research program in control theory was begun by Nick Declaris. This attracted a number of outstanding graduate students, some of whom are present members of the electrical engineering faculty.
- An important research event was the establishment of the interdisciplinary Laboratory of Plasma Studies as a College facility. Eight members of the electrical engineering faculty contributed in a major way to its early development. Initial experiments in the generation, characterization, and control of intense relativistic electron beams were performed in the Mitchell Street Laboratory. By 1970, work had expanded to Upson and Grumman Halls, and three experimental groups were involved in studying applications of beams to fusion and high-power microwave radiation.

Left: The Cornell Cable Project, carried out during the early 1960s, used a high-voltage cable-testing facility erected near the High Voltage Laboratory. The project was sponsored by the Edison Electric Institute, an industrial group.

Below: An early plasma physics experiment in Phillips Hall was a forerunner of research at the Laboratory of Plasma Studies. The equipment included a vacuum switch apparatus.



In 1963 Booker resigned to become

head of the Department of Electrophysics at the University of California at La Jolla, and Glen Wade served as director until he left for the University of California at Santa Barbara in 1965. Throughout the Booker and Wade administrations, Erickson was the assistant director. (After that Erickson served a five-year term as associate dean of the College before returning to the School as a full-time professor.)

During Wade's short time in office, five new faculty members were appointed; four of them—Joseph M. Ballantyne, Richard L. Liboff, John A. Nation, and Chung L. Tang—remain as full professors. (In later years, Ballantyne and Nation became, in turn, directors of the School.)

In 1965 Herbert J. Carlin became director and served until 1975 except for a one-year leave in 1972-73 when Dalman was acting director. Joseph L. Rosson was the assistant director during this period. (In 1975 he became associate director, a position he still holds.)

During the years of Carlin's administration through 1973, sixteen new faculty members were recruited; their areas of interest leaned somewhat more toward the *systems* area to offset the *electrophysics* bent of the Wade years. Eight of these appointees—Toby Berger, Robert R. Capranica, Donald T. Farley, Terrence L. Fine, Jeffrey Frey, Walter H. Ku, Charles A. Lee, and Charles B. Wharton—remain in the School as full professors and one, Robert J. Thomas, is an associate professor. Another full professor, Neil Brice, was lost in a tragic air disaster in 1974.

The overall result of this period of vigorous recruitment was the establishment of a brilliant young faculty with a wide variety of research interests in modern electrical engineering theory and practice. This expertise, when coupled with the experience and competence of a distinguished senior faculty, created an assembly of educators whose enterprise and growth would cause the School to be placed among the top electrical engineering schools in the United States by the end of the 1970s.

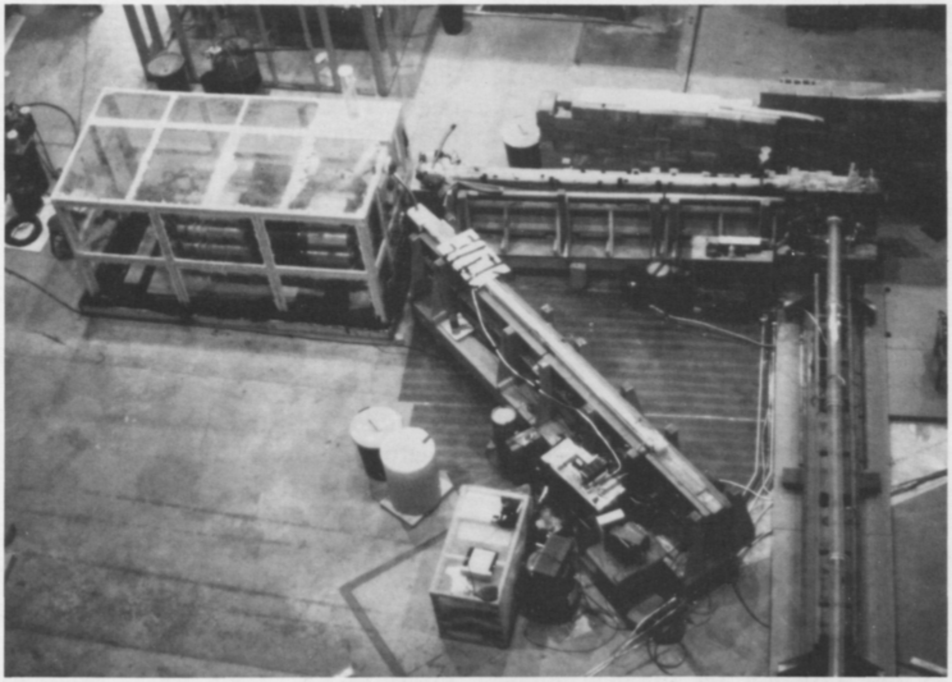
CONTINUING PROGRESS THROUGH THE SEVENTIES

The last two years of Carlin's administration were characterized by a reorganization of the governance of the School. The long-established Faculty Committee continued to serve as an academic-standards and curriculum-study body, and a powerful new Policy Committee was established. Procedures were established to provide faculty involvement in the recruitment and promotion of faculty members.

On the technical side, the national energy crisis of the early 1970s brought new emphases. One of these was fusion-related electron- and ion-beam research carried out in the University's Laboratory of Plasma Studies. (Since 1975, Ravindra N. Sudan has been director of LPS; John A. Nation was associate director until he assumed the directorship of the School of Electrical Engineering). Also, several faculty members gave attention to areas such as alternative energy sources, the Hydrogen Economy, and the electric automobile.

The increased activity extended to many other fields. Application of the techniques of feedback control theory to power-systems analysis led to the formation of a vigorous power-control group in the School. Problems related to power and energy, and to communications and control systems in general, combined with the expansion of information networks to generate the formation of a strong faculty group in the field of information, decision, and estimation theory. Two courses in electronic-circuit design (still among the most popular elective courses in electrical engineering) were introduced by Nelson H. Bryant. Under the leadership of H. C. Torng and Norman M. Vrana, the burgeoning field of computer engineering began to add a new dimension to the School's program, as a field in its own right and also as an essential adjunct to the development of the other new enterprises.

These projects were in full swing when G. Conrad Dalman became director in 1975, and they were quickly followed by many new developments. These included the construction, on the top floor of Phillips Hall, of a



Left: A photograph taken about 1968, soon after the Laboratory of Plasma Studies was established in the Mitchell Street Laboratory, shows equipment for relativistic electron-beam experiments. The makeshift high-voltage power supply at the extreme left prompted Dean Andrew Schultz, Jr., to comment admiringly, "These E.E.'s are fast on their feet!"

Below: The national submicron facility, established in 1978, moved into an especially designed new building in 1981.

complex of "clean rooms" for crystal growth and the processing of semiconductor materials and devices; a move toward the establishment of bioelectronic research; expansion of quantum electronics and optoelectronics research by means of very-high-power lasers; the introduction of research in integrated optics; the development of new courses in digital systems; and an enhancement of the activities in radiophysics and space research. Four assistant professors were added to the faculty (one of them, Michael C. Kelley, remains as a full professor).

In late 1976 a major proposal for the establishment at Cornell of a national facility for research in submicron structures was made in response to an invitation from the National Science Foundation. The proposal, prepared by Joseph M. Ballantyne with the help of colleagues in several departments, was submitted in January of 1977, and at a memorable School faculty meeting the following June, Ballantyne announced that the $5-million, five-year grant would be awarded to Cornell. (MIT and the University of California at Berkeley were the closest competitors.) The National Research and Resource Facility for Submicron Structures was founded.

The new project generated a flurry of events. In 1978 Edward D. Wolf was appointed a full professor and director of the new laboratory, which soon came to be known as NRRFSS, or the National Submicron Facility. In 1979 Thomas E. Everhart (author of the "runner-up" Berkeley proposal) became dean of the Cornell College of Engineering and also a professor of electrical engineering. The facility was housed in the extensively renovated top floor of Phillips Hall while plans for a highly specialized adjacent building were drawn up. Ground was broken in March, 1980, and the $3.8-million Knight Laboratory (named for Cornell alumnus and Presidential Advisor Lester B. Knight) was dedicated in October, 1981.

The establishment of NRRFSS brought national and international prominence to Cornell as an advanced center for research in the fundamental physics and materials problems related to thin-film electronic structures in the submicrometer regime, and as a facility to advance the art of submicrometer fabrication technology. In addition to stimulating the interests and activities of both graduate and undergraduate students, the new laboratory provided exciting and challenging opportunities for a wide program of research. Cornell people were joined by researchers from laboratories across the country who came to work at the facility through the User Research Program that had been mandated by the original NSF grant. As the decade ended, some two dozen groups had initiated this mutually beneficial association with NRRFSS.

A related industrial-affiliates program, coordinated through NRRFSS, was established by the School in 1978 as the Program on Submicrometer Structures (PROSUS). The purposes are to provide information exchange, promote a strengthening of interactions between the University and industry, and encourage industrial funding in support of research and academic programs. Some thirty industrial organizations have become affiliates in the program.

THE PRESENT: A TIME OF GROWTH AND RAPID CHANGE

Joseph M. Ballantyne became director of the School in 1980, after Dalman had completed his five-year term. The relatively short time during which Ballantyne headed the School (he became the University's vice-president for research and advanced studies in the summer of 1984), was marked by unprecedented growth in the number of electrical engineering students. Currently there are some 420 undergraduates majoring in electrical engineering, and about 240 graduate students. There was also a large number of young faculty members appointed to tenure-track positions: David F. Delchamps, Chris Heegard, Marija Ilić-Spong, C. Richard Johnson, Jr., Kevin Karplus, Paul Kintner, J. Peter Krusius, Franklin T. Luk, Clifford R. Pollock, Anthony P. Reeves, Charles E. Seyler, Jr., John R. Treichler, Jean C. Walrand, S. Simon Wong, and Sally L. Wood. Two senior professors, Tor Hagfors and Noel C. MacDonald, also joined the School. Of course, the influx of new professors has been offset, to some extent, by retirements and resignations. The increased number of students makes it difficult to provide needed space and meet educational priorities.

The impetus for the growth in the electrical engineering program is the remarkable expansion of the field. In the years before World War II, studies in the School were divided between the "power option" and the "electronics option." The tables (on pages 25 and 28) listing the areas of concentration now offered and the research interests of the faculty show how extensive the program has become.

A major factor in this transformation has been the "computer revolution," which encompasses such areas as computer engineering, digital-signal processing, computer graphics, computer-aided design, very-large-scale integrated circuits (VLSI), microprocessor systems, and quantum and solid-state electronics. Through the generosity of several computer manufacturers and by discrete purchases, the School is now well equipped with computer facilities. Each faculty member has a terminal that is interconnected with the Phillips Hall network and is thus available for both research and teaching purposes. The facilities include several mid-sized computers with large files, graphics hardware, and a network of powerful 32-bit engineering work stations. Students also have access to these components from terminals in various laboratories and in several rooms used exclusively for this purpose. Although the University's central system is available as needed, most of the computing requirements at the School are met by the in-house network. Several members of the plasma-studies group (Sudan, Seyler, and Nation) also have access to the Lawrence Livermore National Laboratory CRAY system.

Computer capability is the essential element in the recently added Kettering Energy Systems Laboratory, a facility that promises to restore Cornell's early prominence in the power and energy field. Designed and assembled under the supervision of the School's power-control group, and funded by a grant from the Kettering Foundation, the facility was dedicated in the fall of 1983 and has already earned a reputation as a unique electric-power research tool and as an exciting adjunct to educational capability in that field. The laboratory relies on powerful digital/analog computer techniques to obtain solutions to the real-time operating problems associated with today's highly complex bulk electric-power systems.

Another significant development occurred in the fall of 1982, when the Semiconductor Research Corporation (SRC) selected Cornell as the site of one of its first and largest "centers of excellence" for research on microscience and technology that is essential to the development of VLSI circuits. Jeffrey Frey of the School faculty served as acting director of the million-dollar-per-year program for two years, and in 1984 Noel C. MacDonald was appointed director and also joined the faculty.

John A. Nation, who became director of the School in August of 1984, has the distinction of leading the advance into the second century. At this milestone, a distinguished faculty and an outstanding body of alumni can look back with pride and forward with confidence, for electrical engineering at Cornell has accrued a history of remarkable accomplishment, has maintained its position of educational leadership through the years, and is today a strong presence in a field that has developed beyond anything imaginable one hundred years ago.

Simpson Linke, professor of electrical engineering, has experienced much of the history he discusses in this article; he has been at Cornell for more than thirty-eight years. He began graduate study here in 1946, following World War II service in the Army Signal Corps, and after receiving the M.E.E. degree, joined the faculty in 1949. He had earned an undergraduate degree in electrical engineering at the University of Tennessee in 1941 and had worked for a year with the electric utilities board in Knoxville.

At Cornell he supervised the Power Network Calculator Facility until 1960, and he has served as assistant director of the Laboratory of Plasma Studies and graduate faculty representative in electrical engineering. He has spent sabbatical leaves with the Philadelphia Electric Company and the National Science Foundation RANN Program. During the 1970s he organized and chaired the International Symposium on the Hydrogen Economy, held at Cornell, and a joint Cornell—Los Alamos Scientific Laboratory seminar on superconducting magnetic energy storage.

Linke is a life senior member of the Institute of Electrical and Electronics Engineers, and a member of the International Conference on Large High Voltage Electric Systems (CIGRE), the American Association for the Advncement of Science, the American Association of University Professors, Sigma Xi, and Eta Kappa Nu.

PEOPLE, PROGRAMS, PROGRESS
The Outlook for Electrical Engineering at Cornell

by Joseph M. Ballantyne and John A. Nation

Over the past century, as electricity has transformed the civilized world, electrical studies have burgeoned. At Cornell, where one of the very first programs in electrical engineering was formed, the rapid development continues today. The centennial is a good time for us at the School of Electrical Engineering to pause for a look around, to assess our progress and see where our paths may be leading.

Our primary mission is to provide the opportunity for our students to obtain an excellent education. How can we assess our progress in this direction? The most commonly accepted measures are periodic rankings of the quality of faculties and the educational effectiveness of programs, as determined by national surveys of peer faculty members. In these bald terms, Cornell's electrical engineering program ranks about fifth among more than ninety leading departments.

This does not, of course, tell the whole story. Many factors account for our successes, and the outcome of many challenges and opportunities will influence our future.

FACULTY STRENGTH: A FUNDAMENTAL ASSET

An institution can only be as good as its faculty, and in this regard the School of Electrical Engineering at Cornell is clearly a leader in its field. A review of recent personnel changes reveals the increasing strength of the faculty, a strength that is sustained by senior members and invigorated by the infusion of exceptional new talent.

During the last four years, changes in the faculty have included the retirement of three long-time stalwarts: Paul Ankrum, Bill Erickson, and Henry McGaughan. Also, Tom Everhart, who was dean of the College of Engineering as well as a member of our faculty, moved on this past fall to become chancellor of the University of Illinos at Urbana.

Of course, the departure of these people, who contributed so much to our School, also provided the opportunity to introduce new faculty members. Table I, which lists our current faculty, shows in color the names and areas of specialization of our recruits during the last four years. With the exception of Tor Hagfors and Noel MacDonald, who came as directors of large centers (respectively, the National Astronomy and Ionosphere Center, and the new Semiconductor Research Corporation center for the Program on Microscience and Technology), all of these appointees entered as assistant or associate professors. An indication of the high quality of these new faculty members is that last year five of them were among the two hundred engineers and scientists in the United States to be selected by the National Science Foundation as recipients of the newly established Presidential Young Investigator Awards. (The awards are for five years and have a maximum value of $100,000 a year, of which $37,500 must come from industry in the form of matching funds: all of our PYIs have received this industrial support.)

We are also pleased to note that two of our faculty members, Mike Kelley and David Delchamps, have been recent recipients of the Cornell Society of Engineers' annual Excellence in Engineering Teaching Award. Both of

Table I. The Faculty and Their Research Interests

Joseph M. Ballantyne: optoelectronic materials and devices, integrated optics, submicrometer lithography
Toby Berger: information theory, signal processing
Ralph Bolgiano, Jr.: tropospheric radiophysics, communication theory
Nelson H. Bryant: electronic circuits, instrumentation
Robert R. Capranica: sensory communication, electrophysiological studies of neural processing, bioelectronics
Herbert J. Carlin: microwave circuits, network theory
G. Conrad Dalman: microwave solid-state devices and circuits
David F. Delchamps: linear and nonlinear dynamical systems, stochastic systems, control theory
Lester F. Eastman: microwave and optical solid-state devices, compound semiconductor epitaxy and processing
Donald T. Farley: ionospheric physics, radio propagation
Terrence L. Fine: decision theory, estimation, foundations of probability
Jeffrey Frey: semiconductor materials and device physics, integrated electronics, microwave semiconductor devices
Tor Hagfors: lunar and planetary radar astronomy, scattering from ionospheric irregularities, plasma physics, detection theory
Chris Heegard: information theory, coding theory, digital communications, VLSI systems
Marija Ilić-Spong: mathematical modeling and control of electric power systems, control applications in robotics
C. Richard Johnson, Jr.: adaptive parameter estimation applied to digital control, system identification, digital signal processing
Kevin Karplus: VLSI, computer music, computer-aided design
Michael C. Kelley: space plasma physics, rocket and satellite instrumentation
Myunghwan Kim: bioelectronics, control theory
Paul Kintner: space plasma physics, digital signal processing
J. Peter Krusius: VLSI and submicron technology, CAD for VLSI
Walter H. Ku: active and microwave circuit design, digital signal processing
Charles A. Lee: solid-state physics and devices
Richard L. Liboff: kinetic theory, plasma physics, electrodynamics, quantum mechanics
Simpson Linke: energy systems, high-voltage transmission
Franklin T. Luk: numerical analysis
Noel C. MacDonald: electron-beam technology
Paul R. McIsaac: electromagnetic theory, microwave circuits and devices
John A. Nation: plasma physics, high-energy electron beams
Benjamin Nichols: educational techniques
Clifford R. Pollock: laser engineering, quantum electronics, color-center physics, molecular spectroscopy, fiber optics
Christopher Pottle: computer-aided design, power-system simulation, network theory
Anthony P. Reeves: parallel computer systems, computer vision
Joseph L. Rosson: power engineering, instrumentation
Charles E. Seyler, Jr.: plasma physics, thermonuclear fusion, high-power beams, space plasmas
Ravindra N. Sudan: plasma physics, thermonuclear fusion, high-power electron and ion-beam physics
Chung L. Tang: lasers, quantum electronics
Robert J. Thomas: applications of control theory to power systems
James S. Thorp: applications of optimization and control theory to power systems
Hwa-Chung Torng: computer engineering, computer networks, telecommunications engineering
John R. Treichler: digital signal processing, digital filtering, adaptive systems
Norman M. Vrana: switching theory, central processor design, microprocessor systems
Charles B. Wharton: plasma physics, microwave diagnostics
Edward D. Wolf: microminiaturization science and technology
George J. Wolga: lasers, atomic and molecular physics, applied spectroscopy
S. Simon Wong: high-speed silicon integrated circuit technology
Sally L. Wood: statistical signal processing, image processing, pattern recognition, computer vision, biological signal analysis

The scope of the School of Electrical Engineering is suggested by Table I, which lists the current faculty members and the speciality areas in which they teach and conduct research. The names of professors appointed during the past four years are shown in color.

these selections (made on the basis of student evaluations) are noteworthy: Mike was the first electrical engineering professor to receive the honor, and David's award was made after he had been on the faculty for only one year.

Other members of our faculty who have received honors recently include Rick Johnson and Toby Berger. Eta Kappa Nu, the national honorary society in electrical engineering, named Rick the Outstanding Young Electrical Engineer of 1982, and also the C. Holmes MacDonald Outstanding Teacher of 1983. Toby received the Frederick E. Terman Award of the American Society of Engineering Education.

CORNELL ENGINEERS AS STUDENTS AND ALUMNI

We are fortunate in the quality and breadth of interests and abilities of our students. Two of them, for example, were among thirty-five seniors throughout the University who were named last spring as the first Presidential Scholars in recognition of high academic performance, intellectual

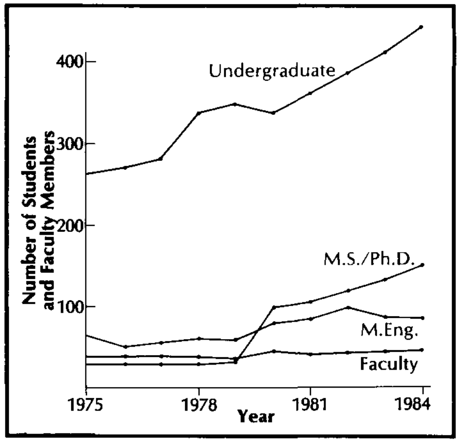


Figure 1. Enrollments in recent years in electrical engineering programs at Cornell, compared with the size of the faculty. (The decline in the number of M.Eng. students in 1983 is considered temporary, the result of the discontinuation of a program sponsored by AT&T before the corporate breakup.)

curiosity, and leadership. Edward Lu was secretary of the electrical engineering honorary Eta Kappa Nu, chairman of that society's tutoring committee, and a member of the Cornell wrestling team; Sarah Jane Skinner served as an Eta Kappa Nu tutor, and she was a member of the Sage Chapel Choir. A current senior, Rebecca Ann Greenberg, is the top student in the College.

On campus, the student branch of the IEEE is very strong; with Eta Kappa Nu, it has developed a wide variety of activities ranging from social events to the new Corporate Window program. The Corporate Window is notable as a way of bringing our students into contact with engineers and managers from industry; in on-campus meetings the students hear about corporate programs and opportunities, and find out how their predecessors have fared in corporate America. As expected, our alumni have actively participated in this and other recruiting programs.

Our students' continuing interest in the School after they graduate is particularly gratifying. The development of strong relationships between alumni and the faculty and staff is encouraging in its prospects for good relationships with tomorrow's industrial and government leaders.

RISING ENROLLMENTS AND THEIR EFFECTS

A matter of considerable concern to the School is the recent and projected rise in enrollment (see Figure 1).

An interesting comparison (not shown in the figure) is the number of undergraduates now and in 1954-55, when the School moved into Phillips Hall: in 1984–85 there are about 420 electrical engineering majors, and in 1954–55 there were only about 140 undergraduates in the upper three years of the electrical engineering degree program as it was then organized. Much of this increase has occurred in the last five years. The graduate enrollment has also risen, from essentially zero in 1954–55 to 244. This growth—a tripling of the undergraduate enrollment and a total enrollment more than four and one-half times larger than it was when Phillips Hall was built—has placed severe strains on our facilities, especially in the teaching laboratories. For example, the required junior-year laboratory course now meets seven times a week and requires twelve teaching assistants. Similarly, the introductory microprocessor course has an enrollment of about 220 and has fifteen sections.

The situation may get worse. Currently we attract more than 40 percent of the incoming freshman engineering class, and if this trend continues, 280 students who are now freshmen will seek junior-year enrollment in electrical engineering! The heavy faculty and support-staff requirements, the maintenance of equipment, and the need to provide adequate classroom and laboratory space present problems that will have to be solved in the immediate future.

We believe we need more than double the space available in Phillips Hall if we are to continue to meet the demands placed on us. The short-range solution to the space problem is to expand the electrical engineering facility into one of two additional floors being planned for Upson Hall. This will add about 12,000 square feet of space for electrical engineering. Seeking a long-range solution is a considerably more difficult task that will involve Cornell electrical engineers on the campus and beyond.

One encouraging aspect of the growth in enrollment is the very rapid increase in the numbers of women and minority students. In 1983-84 there were sixty-one women and 101 minority students in the undergraduate electrical engineering program.

Phillips Hall at upper left is adjoined by Knight Laboratory, the submicron facility (with its logo painted on the roof). One idea for future expansion is to build an addition to Phillips Hall along the road.

Another beneficial aspect of the enrollment picture is the rising number of graduate students, an essential factor in our research program as well as our educational effectiveness, since we rely on graduate teaching assistants. This year we have 142 M.S./Ph.D. students working in faculty-directed research programs. We would like to increase this number by forty to sixty, so as to reach an average of four and one-half to five graduate students per faculty member, a ratio we consider optimal for our research programs. Here again the space limitations in Phillips Hall are a factor, since they inhibit the growth of research activity.

The professional Master of Engineering (Electrical) degree program is also strong, despite what appears in Figure 1 to be a recent decline followed by a leveling-off of enrollment. The data are misleading because the program was greatly affected by the sudden discontinuation of the Bell Laboratories One Year on Campus (OYOC) program as a result of the AT&T breakup; in the final year of OYOC, nearly one-half of our M.Eng. students came through that program. The effect of the discontinuation has been largely offset by an increase in the number of non-Cornell baccalaureate graduates seeking admission to the M.Eng. program.

Figure 2

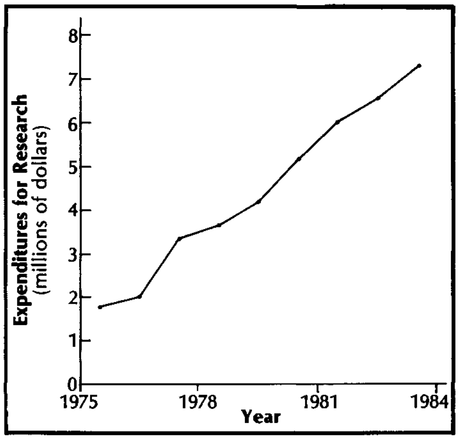


Figure 2. The increasing level of expenditures for research at the School of Electrical Engineering. The breadth of the program is indicated in Table II.

AT THE FOREFRONT OF SCIENCE AND TECHNOLOGY

The research interests represented within the School cover a broad spectrum of applied and theoretical topics, ranging from modern physics and its applications in VLSI technology, to work on systems, including large-scale systems analysis. Funding for project research has shown a continual rise, as illustrated in Figure 2. Expenditures in 1983-84 exceeded $7 million, which amounts to an average of approximately $175,000 per faculty member. The real growth in funding over the period shown in the figure is about 9 percent per year.

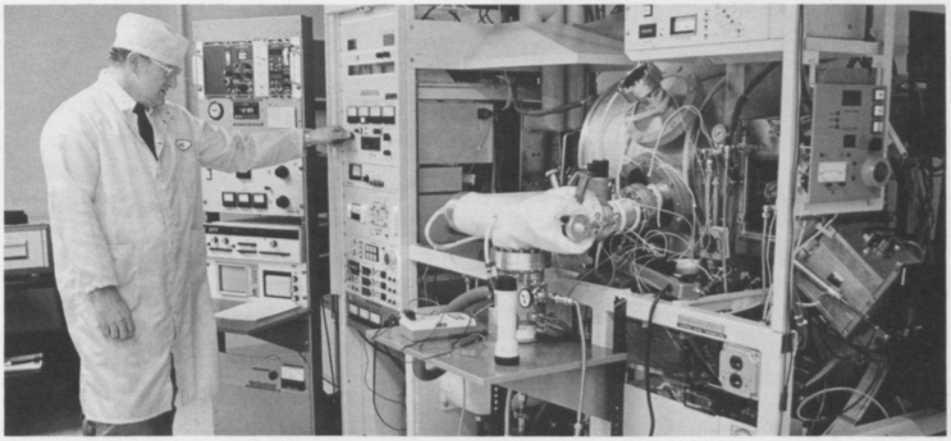
Among the changes we have seen in the last several years has been a heightened interest in the computer-engineering stem of our program. This has been accompanied by an increase in the faculty in this and closely related research areas, such as digital signal processing. These changes have been made visible by the acquisition of four new computers in the School. Two of these, a VAX 11/780 and a Data General MV8000, provide computing and word-processing capability for the School as a whole. The third, a VAX 11/750, serves the new Kettering Energy Systems Laboratory, a facility used to study energy conversion, transmission, computer-aided protection and controls, and communication in relation to the design and operation of large interconnected systems, particularly electric utility systems. A Harris 800 computer system has been donated to the School to serve the computing needs of those in the area of space plasma research.

Table II.
RESEARCH AREAS OF INTEREST WITHIN THE SCHOOL

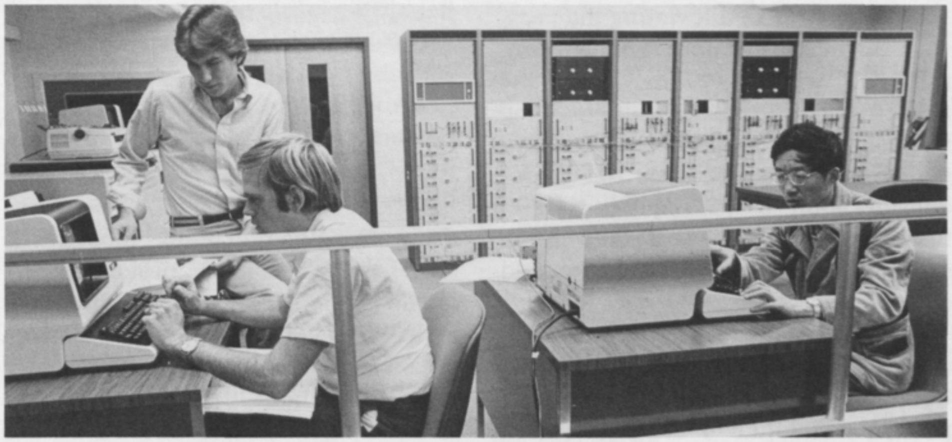
Bioelectronics and Bioelectric Systems
Communications, Information Theory, Decision Theory
Computer Engineering
Control and Systems Theory
Electromagnetic Theory and Applications
Electronic Circuits and Instrumentation
Energy Conversion and Power Systems
Integrated Circuits
Microwave Semiconductors: Circuits and Device Physics
Network and System Design
Plasma Physics and Applications
Quantum Electronics and Optical Physics
Radiophysics and Geophysical Plasmas
Semiconductor Materials for Electronic Devices
Signal Processing
Submicrometer Technology

The microelectronics program has also undergone major changes. Activity has increased rapidly since the formation of the National Research and Resource Facility for Submicron Structures (NRRFSS) in the late 1970s. A major boost came from the recent establishment of the Program in Microscience and Technology, which receives more than $1.4 million a year in research support through the Center of Excellence program of the Semiconductor Research Corporation.

The School has strong research programs in many other areas, of course (see Table II). In most of these areas the researchers are working at the cutting edge of present-day physics and technology. Groups in several specialty fields receive their principal support from the federal government; examples are plasma physics, and radiophysics and geophysical plasmas. In these two areas alone, research support is in excess of $2.3 million a year. Programs in quantum electronics, microwave electronics, and semiconductor materials and their applications are also strong and have substantial research funding.



Left: The recently added National Research and Resource Facility for Submicron Structures is important to many researchers in the School. Edward D. Wolf, a member of the electrical engineering faculty, is the director; he is shown in one of the facility's clean laboratories.



Left below: Another important recent addition is the Kettering Energy Systems Laboratory, a unique facility that allows computer simulation of systems such as those for bulk power transmission.

Perhaps the greatest changes in research activity within the School have occurred in the systems area, largely as a result of the influx of new faculty members. In fact, four of the five recently appointed electrical engineering professors who received PYI awards specialize in research that falls in this general category. These additions to our faculty serve to augment an already strong base in areas such as communications, network and system design, signal processing, and information theory.

FINDING SOLUTIONS TO LOOMING PROBLEMS

Our continued growth augurs well for the future of the School, but to reach our potential we will require more space and expansion of our faculty and staff. At the graduate level, we foresee an increase in the number of students and therefore a need for more research support specialists. At the undergraduate level, problems created by the expanding enrollment will reach a crisis level in the near future; we must improve our instructional facilities and programs in order to restore the quality of educational opportunity that was available before the rapid expansion of interest in the field.

A partial solution may be found in a feature of our instructional program that seems likely to grow in the future: a sharing of resources, in both facilities and faculty, among various academic units of the University. (Arrangements of this kind developed partly because they help meet problems caused by differing rates at which changes in demand occur—on the one hand, student demand for instruction in particular fields, and on the other hand, industrial demand for employees in particular specialty areas. A further factor is is the long time scale associated with a working career.) Cooperative teaching arrangements are feasible between faculty members in our School and in closely related units such as Applied and Engineering Physics, and Operations Research and Industrial Engineering. Policy decisions concerning the sharing of teaching responsibilities will be needed in the near future.

Teaching laboratories in the School of Electrical Engineering have been upgraded in recent years. This is a digital-systems laboratory.

"... to reach our potential we will require more space and expansion of our faculty and staff."

Another way of alleviating the pressure of increasing undergraduate enrollment would be to raise the academic requirements for remaining in good standing as an electrical engineering major. A proposal under consideration is to require maintenance of a higher grade-point average and higher minimum grades in the field courses.

Additional help may come as a result of stronger and broader-based interaction with industry and alumni. An important development in the past few years has been a growth in industrial support for both research and teaching activities, and we believe this growth will continue, not only at our School, but in other parts of the University and in higher education in general.

The most dramatic change in our School has been in our teaching laboratories; as a result of substantial industrial gifts, we now have extremely good, modern equipment for use in most of our courses. Industrial support of our teaching function has amounted to about $750,000 a year for the past two years and continues to show strength. Inevitably, though, we have found a new problem accompanying this benefit: how to maintain these excellent facilities. Typically, a maintenance contract requires an annual payment of about 10 percent of the cost of the equipment, an amount substantially beyond our means. The solution of this problem has high priority in our planning for the coming years.

BEGINNING THE SECOND CENTURY OF OUR HISTORY

Problems must be solved, but new ventures are also on our minds as we look to the future. The prospect of enlarging the electrical engineering facility is a stimulus as well as a necessity, and we perceive opportunities in this and other possibilities.

Two of these opportunities are in conjunction with major initiatives of the University. One is a proposal to establish at Cornell a Theory and Simulation Science and Engineering Center that would provide supercomputer facilities for research. Many members of our electrical engineering faculty are interested in the program, to be directed by Ken Wilson of the physics department. Ravi Sudan of our School is co-principal investigator in this project.

The second initiative is a proposal to form an Engineering Research Center to promote the investigation of aspects of engineering and manufacturing. This center would be closely affiliated with the already functioning Cornell Manufacturing Engineering and Productivity Program (COMEPP). Electrical engineering faculty members who are involved in the effort have proposed an interdisciplinary program to investigate the fundamental issues related to the automated manufacture of integrated circuits that have features with dimensions in the submicrometer size range. The proposed program includes projects to develop submicrometer processes, automated metrology techniques, and automated process control for the manufacture of a new class of integrated circuits.

A further possibility the School is exploring is the initiation of an industrial affiliates' program in the area of signal processing and control systems. It would be similar to the Program on Submicrometer Structures (PROSUS) that is operating very successfully in conjunction with NRRFSS, the national submicron facility. We invite companies interested in the proposed program to contact the School for further information.

Ballantyne

Nation

And so our second century begins with a sense of excitement, challenge, and large enterprise. We at the School of Electrical Engineering invite all our alumni to participate in the centennial, celebrating not only past achievements, but future possibilities.

Joseph M. Ballantyne and John A. Nation have led the School of Electrical Engineering in the preparations for the centennial observation, Ballantyne as School director until the summer of 1984, and Nation as the present director.

Ballantyne, who left the directorship to became Cornell's vice-president for research and advanced studies, has been a member of the electrical engineering faculty since 1964. He received his undergraduate education, earning degrees in both mathematics and electrical engineering, at the University of Utah, and he studied at the Massachusetts Institute of Technology for the Ph.D., awarded in 1964.

In addition to serving as School director, Ballantyne played a major part in establishing the National Research and Resource Facility for Submicron Structures (NRRFSS) at Cornell. He was acting director of the facility during its first year in 1977, and is now on the policy board. His research centers on submicrometer studies: lithographic techniques, optoelectronic materials and devices, and integrated optics.

Professional societies to which Ballantyne belongs are the Institute of Electrical and Electronics Engineers (IEEE), the American Institute of Mining, Metallurgical, and Petroleum Engineers, and the American Vacuum Society.

John Nation has been director of the School of Electrical Engineering since the fall of 1984. A specialist in plasma physics and high-energy electron and ion beams, he has also served as associate director of the University's Laboratory of Plasma Studies.

Nation was educated at Imperial College, London, earning the B.Sc. degree in 1957 and the Ph.D. in 1960. After completing his graduate studies, he worked for two years at the nuclear energy facility in Frascati, Italy, and then returned to England as a member of the technical staff of the Central Electricity Generating Board's research laboratories. He came to Cornell in 1965.

He is a fellow of the American Physical Society and a senior member of the IEEE.

A LOOK INTO THE FUTURE

Predictions of Things to Come

by Electrical Engineering Faculty Seers

What changes will electrical engineering bring about by the early years of the twenty-first century? What developments can be anticipated in the discipline, the underlying research, and the applications?

In connection with the observance of the centennial of electrical engineering at Cornell, these questions were put to a number of faculty members, specialists in all the major areas of the discipline. Some responded with considerable interest, and some with misgivings. Some predictions were carefully extrapolated from current experimentation and some are more on the fanciful side. Some of the correspondents extended their predictions well beyond the suggested twenty years or so.

The contributors are: G. Conrad Dalman, Toby Berger, David F. Delchamps, Lester F. Eastman, David A. Hammer, Kevin Karplus, Myunghwan Kim, J. Peter Krusius, Charles A. Lee, Simpson Linke, Noel C. MacDonald, Benjamin Nichols, Clifford R. Pollack, Christopher Pottle, Anthony P. Reeves, Chung L. Tang, Robert J. Thomas, James S. Thorp, and Edward D. Wolf. (Their specialty fields are listed in Table I on page 25.) The names of the professors who prepared the statements are given at the end of each section.

COMPUTERS

Since the mid-1940s, when the history of electronic computers may be considered to have started, the chief centers for computer research have been departments of electrical engineering and, since the 1960s, computer science. Electrical engineers have been the main designers of computer hardware and digital systems. One of the specialties of computer engineers in the 1960s was the integration of small computers into digital systems. Now a knowledge of microprocessors is necessary for all experimental scientists and engineers. The computer (microprocessor) has become a standard part of laboratory equipment either explicitly, as with a personal computer, or implicitly, as part of computer-controlled instruments.

The dramatic changes in computer systems over the past twenty years have been a result of technological improvements rather than new developments in computer architecture. What the mainframe processor of the mid-1960s could do can now be accomplished with a small number of VLSI chips; and within the next five years, processors with all the features of current mainframes will be fabricated on single chips. Beyond this

Associate Professor Anthony P. Reeves (at left) joined the School faculty in 1982 after teaching at universities in the United States, Canada, and Italy. He holds B.Sc. and Ph.D. degrees from the University of Kent at Canterbury in England.

point, however, progress will require more than improvements in technology, though these are still to be anticipated. Because of expected fundamental limits on technology, future advances will require innovative computer architectures.

Designing computer systems has become much more complex over the last few years. In the 1960s chip designers, system programmers, and application programmers could all work fairly independently. Now new systems involve substantial integration of all these stages to take advantage of VLSI technology developments. Furthermore, computer designers now need to be knowledgeable in such areas as performance analysis, fault tolerance, and parallel processing.

In the future, vastly more powerful computer systems will open the way to a variety of new applications. These include advanced simulation; advanced computer graphics, including real-time animation; expert systems; computer vision; and speech understanding. Some milestones for future systems are:

• *A working wafer-scale computer.* Advances in semiconductor technology might make possible the fabrication of complete computer systems on single silicon wafers, but major architecture problems in connection with fault tolerance and testing would have to be solved.

• *A reliable highly parallel computer.* The ultimate technique for achieving higher performance will have to be parallel processing—the use of many processors to solve a single problem—because the speed of light will limit the performance of a single processor. Highly parallel systems will involve more than one hundred processors; in fact, some of today's supercomputers have more than ten thousand processors. In such a system, a single faulty processor could significantly interrupt the computation, and therefore fault-tolerance techniques must be developed to prevent this from happening. Other open research questions include how to distribute tasks among the different processors, and how to interconnnect them.

• *The multi-megaflop desktop workstation.* Powerful desktop workstations with the capabilities of old-style mainframes are becoming commonplace for scientists and engineers. It may be anticipated that processing power for these systems will be multiplied every few years.

• *Fully integrated computer-aided design for digital systems.* The computer is used as a tool in most aspects of the design of computers, but currently there is no single system that can be conveniently used at all levels of the design process.

• *Expert systems for engineering applications.* Expert systems are already emerging for certain applications such as symbolic manipulation, medical diagnosis, and equipment maintenance. Future systems may be expected to assist scientists and engineers in many aspects of their work.

• *Real-time animation.* The display of information in pictorial computer-graphics form is a very effective communication method in many situations. A current drawback is that the generation of quality computer-graphics images requires a vast amount of computer power. For example, many hours of computer time on a powerful machine are required to generate the images for each minute of a computer-animated movie. A milestone will be reached when real-time animation of quality graphics can be done on personal computers.

• *Computer vision and speech processing.* Robots of the future must be able to "see" their environment and should be able to accept voice commands from humans. Current computer-vision systems and speech-processing systems work very well in certain highly constrained environments, but in general situations their performance does not even approach that of humans.—*Anthony P. Reeves*

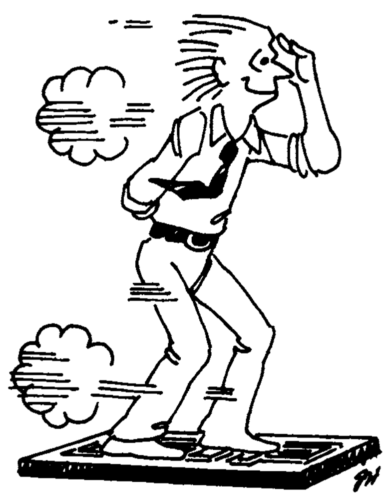
MICROELECTRONICS

Since the invention of the transistor at Bell Laboratories in 1947 and the integrated circuit at Texas Instruments in 1956, the field of microelectronics has experienced an unprecedented technological evolution or, rather, an ongoing succession of micro-revolutions.

Time averages over this sequence show a relationship known as Moore's law: Every characteristic of microelectronic systems becomes twice as good in a fixed period of time. The doubling time for the number of switching elements on one chip, for example, has been only 1.4 years over the past twenty-eight years. Surprisingly, no immediate end to this evolution is in sight. More importantly, the actual impact of microelectronics on information technology, medicine, industrial automation, and food production and processing has barely begun. During the next two decades, practically all areas of human activity will experience the massive impact of microelectronic systems. Projections of what may happen in various lines of development are outlined here.

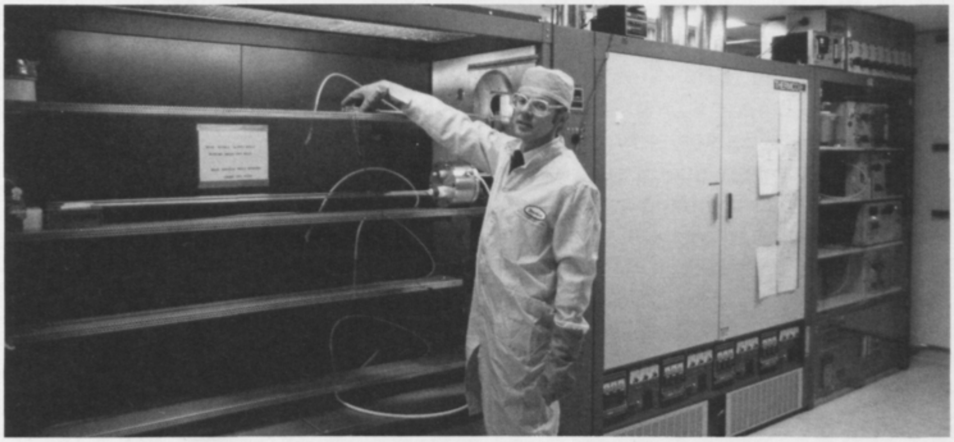
• *Density*. The introduction in 1984 of several prototype silicon memory devices that can store one million bits of information on a single chip continued a trend that started in 1956: a periodic doubling of the density of circuit elements on microchips. A density of 16 million bits per chip should be reached in about 1990, and continued growth along the same curve would take the density up to 16 billion bits per chip twenty years from now.

Such increases require, of course, diminution of the circuit elements. Since density is inversely proportional to the square of the smallest dimension or *feature size* of the circuit elements on a chip, a density of 16 million bits per chip corresponds to a minimum feature size of 0.25 micrometer; for a density of 16 billion bits per chip, feature sizes would have to be as small as 80 angstroms (Å). Several types of functional self-aligned 0.25-micrometer silicon field-effect transistors have been built (for example, at Cornell), but with 80-Å structures, severe three-dimensional quantization effects would be encountered. In fact, for memory densities much greater than 16 million bits per chip, there will have to be a change from structures with two-dimensional integration of the elements on a single chip to two-dimensional structures on a full-wafer scale, or to three-dimensional structures, or to entirely new structures not available today.



• *Speed*. The intrinsic speed of discrete or integrated transistors has not increased as much as density has. By 1953 engineers at Philco had already developed a germanium junction transistor that could be operated at frequencies as high as 100 megahertz (MHz); this year, using modulation-doped gallium arsenide heterojunction devices, researchers at Cornell and other institutions have reached intrinsic microwave frequencies of about 70 gigahertz (GHz). This rate of development corresponds to an average doubling time of 3.3 years. Continuing this trend for twenty more years would take the speeds up to 4.5 terahertz. Frequencies this high may not be possible or useful, however. For example, the next convenient transmission window for electromagnetic waves in the earth atmosphere is 94 GHz.

For electronic applications, though, the decreasing wavelengths will allow the integration of millimeter-wave systems on single chips or, alternatively, on wafer-scale structures. Bell Laboratories have already developed modulation-doped heterojunction logic devices with a switching delay of 10 picoseconds (10^{-12} second) at room temperature, and logic switching delays of one picosecond—probably the ultimate attainable through an entirely "evolutionary" approach—seems possible within a decade. But although electronic phenomena in conventional semiconductor devices are likely to saturate at about one picosecond, optical pulses in the femtosecond (10^{-15} second) range have been reached. Researchers at Cornell have obtained, directly from a laser, pulses only 55 femtoseconds in duration, with repetition rates of 100 MHz. Using additional pulse-compression techniques, IBM researchers have achieved times as short as 12 femtoseconds, with repetition rates of 800 Hz. Combinations



J. Peter Krusius, an associate professor, conducts much of his research in the "clean rooms" of Knight Laboratory. He is a Ph.D. graduate of the Helsinki University of Technology and has worked in research laboratories in Finland and West Germany. He first came to Cornell as a Fulbright fellow in 1979.

of optical and electronic characteristics of semiconductors, including the phenomenon of quantum mechanical tunneling, will make it possible to extend the time scale below one picosecond by the end of the century. In the low femtosecond regime, the Heisenberg uncertainty principle will emerge as a hard constraint.

• *Design*. Because of the complexity of integrated systems, design has become a critical bottleneck, worse than the software crisis encountered in the 1950s and early 1960s before the introduction of software compilers. Despite the introduction of hierarchical computer-aided design (CAD) tools for the design of integrated systems, the potential of microelectronics in design has not been fully exploited. Broadly applicable elements, such as microprocessors and memories, have become dominant as an interim solution.

In the future, the pressure for developing new concepts for systems partitioning, hardware optimization, automatic hardware compilers, deterministic simulation, verification, and testing will force solutions in these areas. During the next five to ten years, for instance, most integrated systems will be designed with improved hierarchical CAD tools. Although restricted classes of hardware compilers will emerge during this time period, universal hardware compilers are not likely to be available before the mid-1990s.

• *Fabrication*. Methods used in integrated circuit fabrication will, for the most part, continue to follow a predictable evolution. Progress to be made in lithography, pattern transfer, thin-film growth, post-growth doping, and process integration will make possible the development of integrated circuits with features in the size range of 100 Å. These techniques will provide means of controlling both lateral and vertical dimensions in silicon chips and also in III-V semiconductor materials such as gallium arsenide.

Advanced research on the fabrication of microstructures will be directed, increasingly, toward novel devices operating in the quantum domain. For structures whose smallest feature size is about 0.5 micrometer,

optical lithography will dominate in standard circuit manufacturing, but electron-beam lithography will find its way into fast-turn-around, custom circuit manufacturing.

Central issues and concerns in industrial microelectronic manufacturing will be closed-loop process control, process automation based on modular fabrication lines, fabrication yield, functional testing, reliability, and economics.

• *Functional capabilities.* Dramatic expansion in the capabilities of microelectronic systems will continue, allowing applications that are impossible today. For technical reasons, future systems will tend to be built on single chips. The factors that are involved include the expected increasing density logic on chips, the limited number of communication channels "off chip" to the rest of the system, and the large difference in speed between "on chip" and "off chip" communication, a difference expressed as speed ratios as large as 1,000:1.

This evolution will lead not only to more powerful single-chip computers, but to true systems solutions. The use of both analog and digital microelectronics will allow integrated signal-processing chips to be built, and combinations of imaging elements and logic will be used in single-chip image processors. A new era in areas such as brain research will be opened up as a result of the ability to fabricate single-chip electrode arrays for recording and stimulating signals in living cells. Eventually this research may help microelectronic systems to "learn" methods of organization, communication, and operation that are found in biological systems.—*J. Peter Krusius*

COMMUNICATIONS: THE OPTICAL AGE

Electrical communication has developed so rapidly in the last few decades that it is now commonplace to see news or sports events on television "live" as they happen, even when they are taking place on the other side of the world, or on the moon. If the recent past is a reasonable indicator of things to come, we can expect all facets of our personal, professional, and financial lives to become increasingly more dependent on communication services—on television for entertainment and education, on facsimile transmission of letters and newspapers, on telephones for business and personal contacts, and on computer networks for data exchange, access to medical information, and the carrying out of

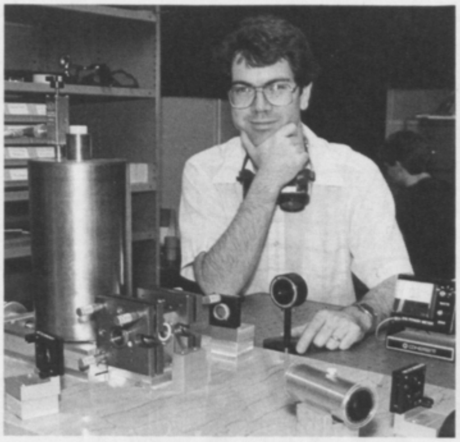
banking operations, to give just a few examples.

The ability to transmit information in large amounts over long distances has been a goal of engineers for many years. Samuel F. B. Morse ushered in the era of electrical communications when he invented and demonstrated the telegraph in 1838; within a few years, commercial operation of the telegraph had spread to all parts of our nation. While the data rate of the telegraph was incredibly slow by today's standards (it operated at a speed of about 4 bits per second), it did provide a means of rapid long-distance communication. The invention of the telephone in 1876 by Alexander Graham Bell expanded the possibilities by allowing direct voice communication. But in the long view of history, there can be little doubt that the most significant communications event of the nineteenth century will be judged to be the discovery of the Maxwell equations of electrodynamics. These fundamental equations correctly predicted the presence of radio waves and led Marconi to the introduction, in 1895, of "wireless" radio communication. For the first time, wide general broadcast of information was possible.

In the ensuing years, the need for transmitting more and more information was the driving force for developing systems with greater bandwidth, or information capacity. Since the amount of information that can be transmitted increases with the carrier-wave frequency, the trend was toward higher and higher frequencies, and an increasingly larger portion of the electromagnetic spectrum was utilized for broadcasting. This led to television, radar, microwave, and satellite links and, most recently, to communication over laser beams operating at optical frequencies.

The future of modern electrical communications will certainly follow these same trends toward increased bandwidth and speed. Decades of work on the transistor and microwave tubes have led to oscillators operating at frequencies from the audio range all the way to hundreds of gigahertz (1 GHz equals 10^9 Hz). Extension to still higher frequencies will prove much harder, and so we are now entering the "optical age," in which information is sent in ultrashort pulses of laser light through tiny glass fibers the size of a human hair. The reason for using lasers is obvious: the information bandwidth of a *single* laser beam is large enough to carry more than *one billion* phone conversations simultaneously.

Many technological problems must be solved before the full bandwidth of a laser beam can be utilized for communication. The information capacity necessary to carry one billion calls would require data bit rates exceeding one trillion pulses per second (10^{12} bps), with each pulse resolvable to well within one picosecond (10^{-12} second). Laser pulses of this duration are now routinely generated in laboratories, but present electronic technology is not capable of responding to signals at this speed; in fact, it is not likely that electronic devices as we know them can be extended to have a response time faster than five picoseconds. This would mean that five or more optical pulses could arrive at an electronic device before the device would even begin to respond.



Clifford R. Pollock, an assistant professor since 1983, earned his doctorate at Rice University. He has held a National Research Council fellowship at the National Bureau of Standards, and this year he won one of the initial Presidential Young Investigator Awards.

To get around this problem, research is being performed on purely optical means of detecting and controlling light. An "optical computer," as it is called, would use light (photons) instead of electrons to control data. The speed of operation would be optimal, since it is the speed of light. Optical networks have been developed that can switch data among various channels, and that can multiplex optical data, effectively reducing the time required for serial operation of the pulses, and we can expect that continuing work will allow the full use of optical bandwidths exceeding 10^{12} bits per second. In the future we can expect to have communication systems operating at optical frequencies with information capacities orders of magnitude greater than those of present systems.—*Clifford R. Pollock*

COMMUNICATIONS 2100

Communications in the twenty-first century will exploit media and embrace applications that stagger the imagination. In the following paragraphs I present a fanciful, and in some respects frightening, scenario of speculations on the nature and uses of communications a century from now. I offer no firm scientific basis for my prognostications; but before you dismiss my musings as mere fantasies, let me remind you that less than seventy years after the first heavier-than-air flight, astronauts returned safely from a romp on the lunar surface after travelling at speeds almost one thousand times greater than those possible from the dawn of history through the mid-1800s. The groundwork for this "giant leap for mankind" was laid in the preceding decades by fundamental advances in physics, mathematics, materials science, and electronics; and I believe that recent breakthroughs in molecular biology, biochemistry, information sciences, and computer technology will engender advances in communications during the next century that will be every bit as spectacular as those we already have witnessed in transportation.

Let us suppose that, just as it became possible for the astronauts to return home one thousand times faster than the rough riders could less than a century before, people will be able to communicate with each other one thousand times faster in the year 2100 than they can now. I am not referring, of course, to a thousand-fold increase in the rate of propagation of messages, since we already know how to transmit them at the speed of light. Nor am I referring to a thousand-fold increase in bandwidth, and hence in the number of information bits per second, that a physical link can transmit. (Indeed, Ameritech's 1984 third-quarter report to shareholders announced that fiber-optic channels already exist that can transmit all 2,700 pages of Webster's unabridged dictionary across Chicago in two seconds.) Rather, I am referring to the rate at which we are capable of *absorbing* information sent to us from another organism or mechanism.

I envision that accelerated knowledge transfer will be achieved in the coming decades by means of various brain-enhancement techniques. These will include direct brain-to-brain communication, brain paralleling, brain transplant, the use of artificial brains and brain supplements, and, most importantly, virtual brain transplant. By virtual brain transplant I mean a form of communication—which I believe will evolve—that will

make it possible to dump part or all of the contents of one's brain into a storage medium and then temporarily insert alternative contents from another brain. In the early stages, the storage media might be banks of human brains similar to the banks for eyes, kidneys, reproductive cells, and so on, to which we already have become somewhat accustomed. As the technology develops, these should give way to artificial "gray-matter" storage media, possibly biochemical in nature and configured like a human brain.

Let us examine some consequences, both positive and negative, of the existence of a high-speed information implementation capability that outstrips today's standards by a factor of, say, 1,000 to 1. An intriguing calculation reveals that the standard eight semesters of undergraduate education, comprising five courses per term at forty-five contact hours per course, requires eighteen hundred hours of class time, but with an information reception rate one thousand times greater, the time required would be one hour and forty-eight minutes! Of course, it will still take time to do creative work, to conduct and report on laboratory experiments, and so on. Also, by then undergraduates may be expected to learn one thousand times as much material as is required at present.

In today's world one's computer files constitute an extension of the mind in the same sense as do one's notes, articles, books, tape recordings, photographs, and video cassettes. All these devices allow us to store crucial information reliably, thereby unburdening the brain so that it can better address more immediate tasks. They also serve as primitive means of interbrain communication via sensory perception mechanisms. In addition, they provide us with the comforting illusion that at least our thoughts have achieved a measure of immortality.

Computer files have the advantage of being relatively easy to revise and update. Moreover, in many computer installations everyone's files are directly accessible by all the other users at any time, except for those files one purposely chooses to encrypt. However, computer files can be inadvertently destroyed by an erroneous command or an unexpected system crash. The crucial point here is that we protect against such catastrophes by regularly backing up these files, say once a week. Given the virtual brain-transplant technology I have postulated, we would be able similarly to back ourselves up at regular intervals. By having backups stored in New

York, Dallas, Tokyo, Pluto, and Andromeda, one would indeed be able to lay claim to a genuine measure of immortality. Even nuclear holocausts or star wars would not necessarily do you in. All you would lose would be that portion of your experience that transpired since the last backup. The sociological, moral, ethical, religious, economic, psychological, and legal consequences are mind-boggling.

The concept of the "self" is in jeopardy. Christiaan Barnard, Barney Clark, William Schroeder, and Baby Fae have conclusively disproved the belief, once sacred to many early civilizations, that the heart is the repository of the essence of a human being. In due time the brain, too, will be dislodged from its seemingly unassailable position as the undisputed sanctuary of human essence. Ancient philosophers agonized over whether or not a ship obtained from the original *Argo* via successive replacement of the planks over many years would still be the *Argo*, especially if all the worn planks had been stored and were then reassembled. It seems that this sort of question may resurface with a vengeance once any and all human parts, including the brain, can be replaced, repaired, or rebuilt. If backups of one's brain were in cold storage and perhaps available to others, then what would it mean to "be" someone? What would it mean to "communicate" with someone else, to "love" someone else, or to "kill" someone else? The elusive search for the human "soul" might assume new importance, to the benefit of humanity.

The capability of storing brain backups would give increasing importance

Professor Toby Berger came to Cornell in 1968 after graduate study at Harvard. He has been a Guggenheim fellow and a fellow of the Japan Society for Promotion of Science and the Ministry of Education of the People's Republic of China. He is a fellow of the IEEE.

to the science of cryptography. Those portions of gray-matter content that one wished to keep secret from others, and perhaps even from oneself, will become intimately connected with the definition of who one is. Their reliable maintenance and their uncompromised security will be essential. The problems of how and to which entity to entrust their encryption will have to be solved in unprecedentedly painstaking, failsafe detail.

The snowball is gathering momentum already. Several small firms devoted exclusively to research and development of biologically and molecularly based computers have sprung up. There have been international symposia on biochemical computing. At the IEEE Centennial Convention in October, 1984, Robert N. Royce, vice-chairman of Intel, stated that "the von Neumann machine may go the way of the brontosaurus and the woolly mammoth" in favor of computers based on biological models. Carver Mead of Cal Tech echoed Royce's sentiments and predicted that biologically based computers will be in production by 1996. The building blocks are beginning to fall into place.

In summary, the problems of how to transmit any single bit of information rapidly and of how to transmit many trillions of bits per second already are solved, and therefore it seems inevitable that the emphasis in communications research and development will shift steadily toward how to convey information from one entity to another in a form that renders it immediately interpretable by the recipient. Progress in the biological and informational sciences eventually will lead to this capability, not only in computer-to-computer communication, which is already being accomplished relatively satisfactorily, but also in computer-to-organism and organism-to-organism communication. The consequences are both thrilling and unsettling.

If your mind is enervated by reading the above, try an extended vacation to the South Pacific. You needn't be concerned about not knowing the native languages of the various island chains. Simply load the appropriate language modules into your brain and they will spring into the forefront of your consciousness. In fact, you could make room for them by temporarily relegating many of your day-to-day problems to cold storage. Isn't that the whole idea behind a vacation anyway?—*Toby Berger*

POWER AND ENERGY

A century ago, when electrical engineering was introduced at Cornell, the principal concern of the new discipline was with power and energy. In the intervening years the standard topics of electric machinery, generation, transmission, and distribution have gained the status of near-classic studies. The application of extensive research and development to the problems of power production and delivery has brought the field to a plateau of high efficiency, virtually absolute reliability, and widespread industrial and residential use. Other factors, such as the energy-conservation programs that followed the oil crisis of the 1970s and several years of a stagnant economy, have contributed to the present-day condition of ample electrical generating reserve capacity in the United States.

Although the national use of electric energy is no longer doubling every decade, as it did in the years from 1918 to 1970, the current growth in demand—approximately 3 percent annually—could wipe out the present surplus capacity by 1990 unless substantial new capacity is installed or increased efficiencies are achieved. A further consideration is that the demand for electric power could increase by an additional 25 percent by the end of this century as electric automobiles, electric rapid-transit vehicles, and heat pumps for residential and industrial heating and processing come into general use. Yet given the controversy over nuclear energy and the present economic disincentives for the construction of large new generating plants, and in view of the fact that, at

best, there is a ten-year delay in bringing a new plant on-line from the time of its conception, we may be well into the next century before new large-scale generating capacity will be available.

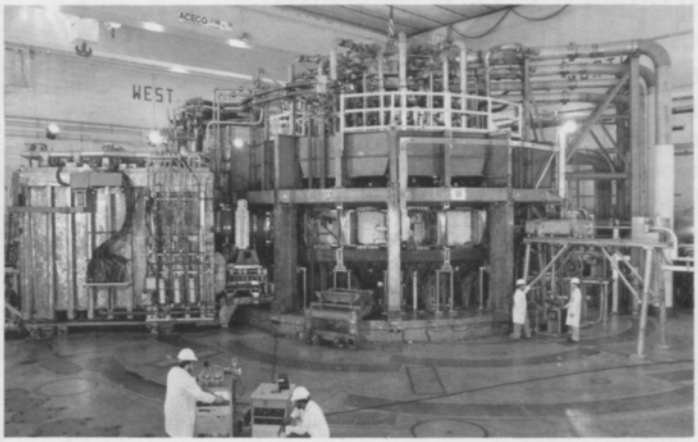
In the meantime, how can the growth in demand be met? Old plants will have to be retrofitted or upgraded. Power network interconnections and long-distance transmission at ultrahigh voltage must be expanded to allow more efficient and more flexible interchange of generating capacity nationwide. And greater use must be made of smaller-scale generating devices such as fuel cells, solar-power converters, medium-sized hydro units, and wind-turbine generators.

The complexities that arise from this diverse set of energy alternatives will introduce major new problems in power control, system protection, and system monitoring. We may expect these problems to be met by extensive application of modern computer technology and advanced control and communication techniques. Better insulating and magnetic materials, and the advent of cryogenic and superconducting technology will also help.

What predictions can be made? We can foresee, for example, the installation of million-volt a.c. and d.c. long-distance overhead transmission lines. Dedicated digital computers, involving advanced microprocessors, will be widely used for the control and protection of local, intermediate, and nation-wide energy networks in hierarchical fashion. Electricity will be metered instantaneously by remote electronic communication techniques. Microprocessors coupled with communication facilities will allow residential and small-business power consumers to choose optimum periods for their use of energy.

Since new large-scale generating capacity will almost certainly be necessary in the United States soon after the turn of the century, it is reasonable to ask what form it might take. The most likely options are increased use of coal and/or nuclear power in the early years, with major contributions possible from solar power shortly thereafter. Fusion power will probably be realized later in the century. We expect that the technical problems associated with nuclear reactor safety and long-term storage of nuclear waste will be solved, and that the cost of these solutions will probably be comparable to the cost of dealing with the pollution resulting from the burning of coal.

The poor fuel efficiency of the present generation of nuclear reactors means that for a long-term solution to our energy needs we must look to breeder fission reactors, fusion reactors, or fission-fusion hybrid systems. Although great advances in understanding and developing controlled



Left above: Evidence that superconducting cables will become a reality is this equivalent 3-phase 1,000-MVA, 138-kV test facility at Brookhaven National Laboratories. The two 375-foot cables operated successfully last October during a two-week continuous life test under conditions that simulated the loading of a typical electric utility system. Large terminations connect the superconducting cables to normal-temperature source and load devices in the outside world.

Right above: This experimental Tokamak Fusion Test Reactor (TFTR) at Princeton University is expected to prove the scientific feasibility of a safe and economic way to generate power. Development of the $314-million machine was part of the U.S. program in magnetic fusion.

Below: David A. Hammer, a Cornell Ph.D., is professor of nuclear science and engineering, associate director of the Laboratory of Plasma Studies, and a member of the graduate Field of Electrical Engineering. (A sketch of Simpson Linke is given on page 23.)

thermonuclear fusion have been made in the last ten to twenty years, fusion technology is still not sufficiently mature to allow predictions about how soon it will be economically competitive with fission reactors for power production. Still, the promise of fusion, with its readily available fuel supply (heavy hydrogen and lithium) and substantially reduced radioactive waste problems compared to fission, makes it highly desirable to introduce this potentially enormous energy source into our generation mix as early as possible.

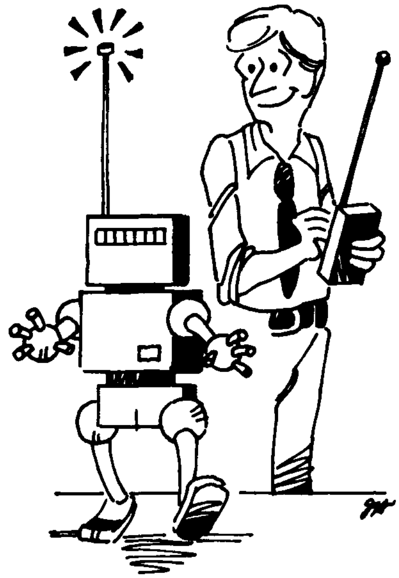
Despite recent major progress in the design of solar converters, substantial research and development is required before there can be economical bulk electric-power production from solar energy. Also, its major advantage of being an environmentally clean energy source is at least partly offset by the fact that large-scale systems would require covering huge land areas with man-made materials.

One might imagine, however, that sometime in the future—not in the twenty years we are trying to foresee, but in perhaps one hundred years—there will be large, remotely located electric-energy parks producing power from a combination of sources. Several breeder fission or fusion reactors with capacities in the range of 1,000 megawatts might be placed in the center of a 100-square-kilometer safety zone covered with solar-electric converters. High-voltage underground superconducting transmission cables might serve as secure conduits for the transfer of these gigawatts of bulk power to distribution centers.—*David A. Hammer and Simpson Linke*

ROBOTICS AND CONTROL

Factories in which complex assembly tasks are performed by robots with a minimum of human intervention are a reasonable expectation for the not-too-distant future, for rapid progress has been made recently in control methods for robots and industrial manipulators. Over the next decade there should be an "explosion" of new robotic technology as a result of ongoing theoretical work and computational advances. So far, though, only rudimentary control schemes have been used, and as a result, the "skills" that a robot can acquire have been severely limited.

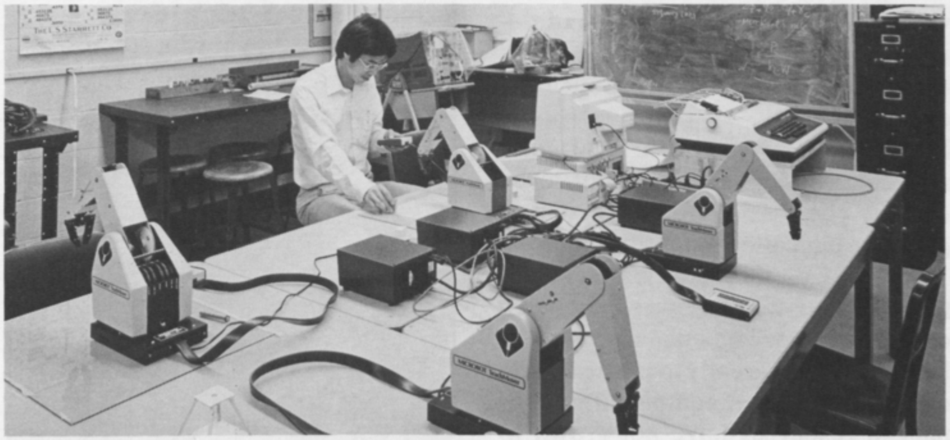
Consider a robotic arm and hand assembly with ten or more joints, each possessing several degrees of freedom. Researchers at AT&T are currently developing robots of this kind that will assemble printed circuit boards at high speeds by performing the apparently simple task of repeatedly placing pegs in appropriately sized holes. The problem of controlling a robotic arm for such a straightforward assembly procedure is extraordinarily complex, however. The robot hand must first grasp an integrated circuit chip and orient it suitably; subsequently, using approximate information about where the holes are located, the robot arm must move the chip into position and perform the minute adjustments necessary for insertion. These final adjustments form the core of a complicated feedback control problem; the robot must gather information about its environment and quickly put this information to use as it "feels" its way into the holes.

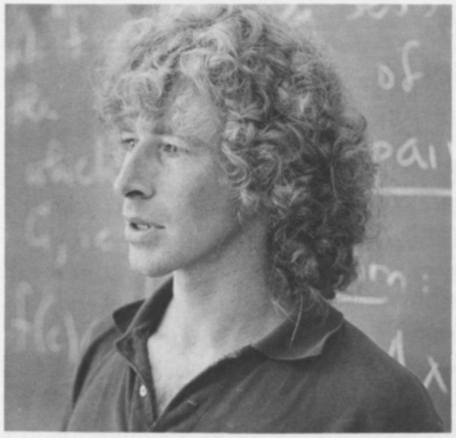


The development of control techniques in electrical engineering research has been, and will continue to be, linked closely with advances in computer technology. Today's smaller and faster computers make possible the real-time control of systems so complex that they could not have been approached even as recently as a decade ago. Today's mainframes and supercomputers make feasible the real-time simulation of large-scale nonlinear systems and also systems—such as those encountered in the control of chemical processes, fluid flow, and flexible robots—that can be modeled using partial differential equations. Furthermore, small, all-purpose microprocessors such as the Motorola 68,000 make possible the on-line decentralized control of complicated mechanisms consisting of interacting subsystems, such as robotic manipulators employed in industrial assembly lines. Future advances in computing technology will enhance the control engineer's ability to develop and understand new theoretical tools and, subsequently, to put these advances to work in an ever-increasing variety of practical situations.

In the case of the ten-joint robot arm and hand, the dynamics are sufficiently complex and nonlinear to warrant a decentralized approach to controlling its behavior, and modern microprocessor technology makes such a strategy feasible. Engineers at General Electric, for example, are working on a robot arm with joints that are independently controlled; each joint has its own high-performance 32-bit microprocessor. To ensure that the joints act in concert, a central processor routes information among these peripheral controllers.

The implementation of new theory and technological tools has consistently lagged far behind their development. Electrical engineers in universities have tended to ignore somewhat the question of how to model physical processes that arise in industry; they have concentrated instead on refining and developing techniques for controlling processes that can be represented by familiar (usually linear) models. Many engineers in industry, on the other hand, are eager to apply new theory to the control of processes for which accurate models do not exist, or to which the growing body of theory does not apply. As a result, it is becoming more difficult for the control *theorist* to assess the applicability of mathematical and algorithmic machinery; significant input from control *practitioners* must be forthcoming if the gap between theory and application is to be closed.





The robotics laboratory at Cornell (above) facilitates research in this rapidly emerging field. David F. Delchamps, who writes about its future, has been an assistant professor of electrical engineering since 1982. This year he received a Presidential Young Investigator Award, which provides research support for five years.

It should be noted that the growth of robotics research has generated new activity in a variety of fields in electrical engineering besides control theory. The problems of tactile and visual sensing have stimulated the areas of computer vision and image processing. Without doubt, it will be quite some time before a robot is developed that can "see" as well as even the most myopic human, but foreseeable advances in multi-dimensional digital signal processing make such a robot a real possibility.—*David F. Delchamps*

UNDERGRADUATE EDUCATION

In considering the future of Cornell education in electrical engineering, I draw on experience that extends back through almost half the one hundred years we are celebrating. At the age of seventeen, in 1937, I entered the School of Electrical Engineering as a freshman; in 1946 I became a graduate-student instructor; and except for occasional years of leave, I have continued to be a member of the school's faculty. It is inevitable that my views of the future are shaped by this long association.

The most obvious changes that have taken place are in the specific specialized subject matter content of our courses. Those students to whom I taught senior courses in electronic circuits in 1947 learned a lot about vacuum tubes but never heard of the yet-to-be-invented transistor. Most of this year's graduates have never seen a vacuum tube. Today's students learn how to design microprocessors rather than induction motors. As new developments take place in technology, they have been and will continue to be incorporated into the curriculum.

These changes in subject matter are not very important in themselves, for the specific technology that the student learns as an undergraduate in electrical engineering will soon be obsolete. The major reason for using up-to-date examples is motivational. If there is one established principle in education, it is that students learn more when they study a subject in which they are interested. Moreover, the process of making continual changes in the curriculum helps to stimulate the faculty.

The faculty has always taken into account the current interests of students, but we also recognize that the rapidity with which technology changes makes it imperative that students be prepared to continue their education after graduation. Some years ago we identified the two basic stems that, as applied mathematics and applied physics, would support future technical developments; we called them electrosystems and electrophysics. The physical connection between these two stems lies in the real world of the laboratory. In satisfying curriculum requirements, every electrical engineering student acquires fundamental knowledge in both of

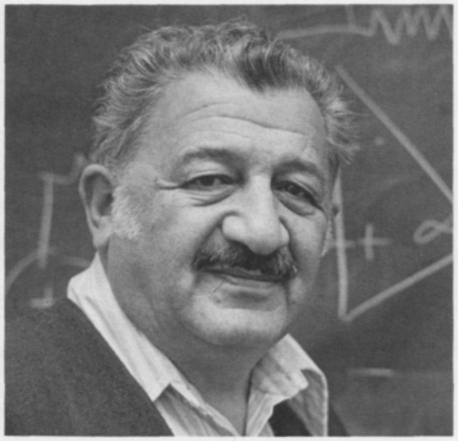
these areas and pursues one of them in greater depth.

This curricular structure may not serve long into the future. For one thing, the relationship of "computer engineering" to electrosystems and electrophysics is ambiguous. Of course, all electrical engineering students these days must learn the basic concepts of logical systems and be able to program and use computers as tools, and in addition, most of them elect to take a year's course work in computer structure and microprocessor systems. The subject matter does not fit neatly into our dualistic conceptual system, however.

But the currently experienced need to accord computers a place in electrical engineering education may be only a small foretaste of the future. Writing in the book-review section of the *New York Times* of October 28, 1984, Cornell alumnus Thomas Pynchon put it pithily: "If our world survives, the next great challenge to watch out for will come—you heard it here first—when the curves of research and development in artificial intelligence, molecular biology and robotics all converge. Oboy." Perhaps we should be thinking now about whether molecular biology will turn out to be one of the basic stems of undergraduate education in our discipline.

At present, the faculty's ability to take any long-range view is very much constrained by immediate pressures. Enrollment has greatly increased while our faculty, space, equipment, and financial resources have not grown to match the demand. Meanwhile, the growth of graduate education and research limits the energy that can be devoted to undergraduates. Cornell has an excellent record of commitment to teaching, but under the circumstances it is hard to do more than attempt to meet immediate needs.

It is easier to discuss what the future in undergraduate education in electrical engineering ought to be than to predict what it will be. In his recent state-of-the-university address, Cornell President Frank H. T. Rhodes set forth as a major goal the provision of "diversified, distinctive, and distinguished undergraduate programs." He pointed out the hazards of professional education, which "can encourage premature concentration on vocational skills at the expense of personal judgement, maturity, and commitment." He argued for professional education that "is large and expansive, having the spirit of liberal arts, setting skills as means with larger ends." Such an education, he said, is concerned not with the job, but with "life and with the social goals the profession promotes and the ethical standards it demands."



Benjamin Nichols, now professor of electrical engineering, first came to Cornell as an undergraduate.

It would be overly optimistic to believe that the objectives set forth by Rhodes will be fully met in the near future. Certainly the evidence of the past and the prospects for the future contemplated by Pynchon (if the world survives) make it ever more urgent that in engineering education time is spent considering the *why* of things as well as the *how*.

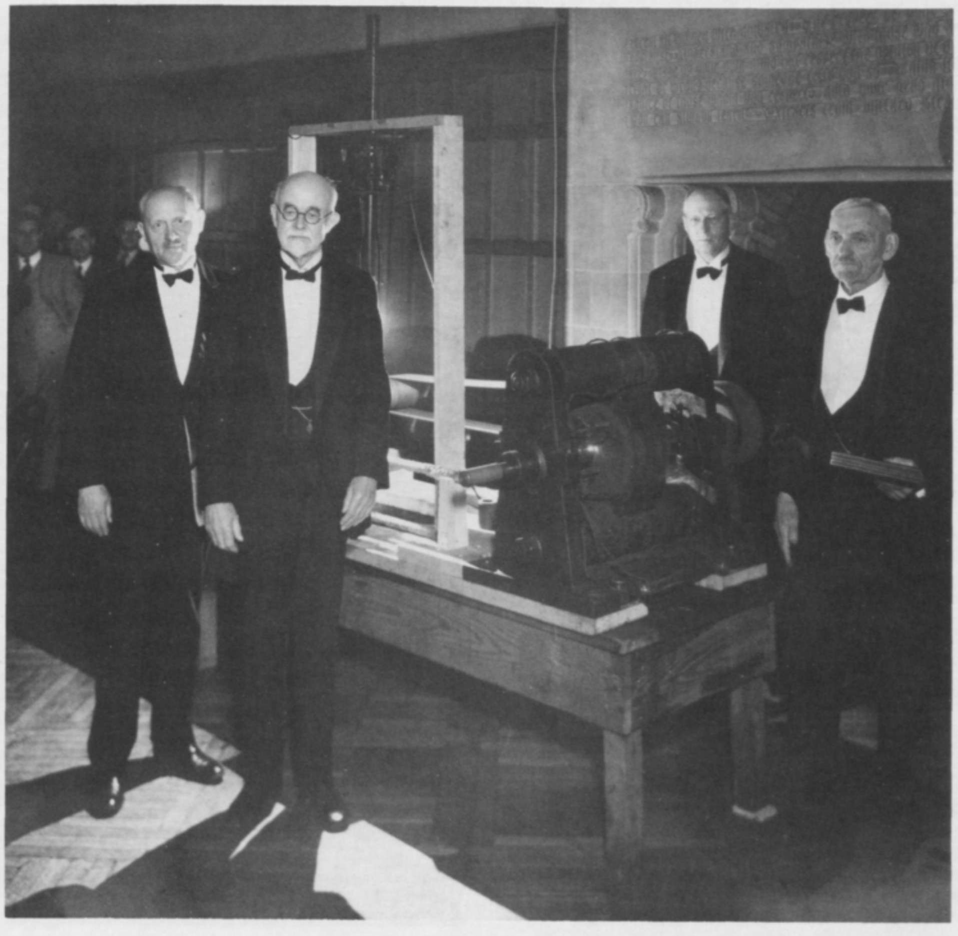
On a more cheerful note, we can anticipate future classes of interesting and more diversified students. In the past few years the percentages of women and minorities in our student body have grown at a rapid rate, and there seems no valid reason why they should not reach levels that are about equal to the percentages of these groups in the general population. It will be exciting to see how the presence of increased numbers of women and people from minority backgrounds changes the nature of our profession.

—Benjamin Nichols

PAST PERFECT
A Collection of E.E. Cornelliana

■ One of the first of many honors received by Cornell professors of electrical engineering was a silver medal awarded to three men who were responsible for building the first American dynamo. The recipients were Professors George S. Moler and William A. Anthony of the electrical engineering faculty and E. L. Nichols, director of the physics department. The medal was in recognition of the historic value of the machine, which had been shown at the Centennial Exhibition in Philadelphia in 1876, at the World's Fair in Chicago in 1893, and at the Universal Exposition in St. Louis in 1904.

What became of the medal, the machine, and their story? A bronze rep-

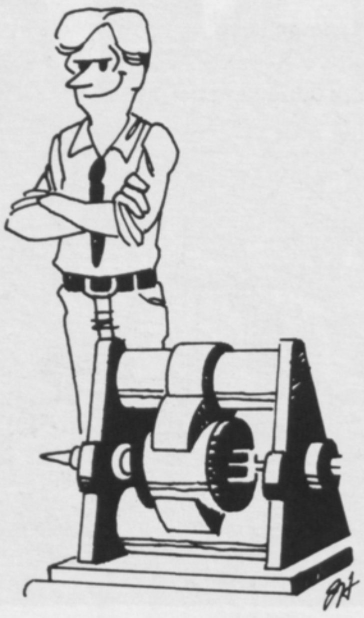


Right: On a ceremonial occasion in 1931, the Cornell dynamo of 1875 was demonstrated by one of its builders, George S. Moler (at right). The single lamp lighting the Memorial Room in Willard Straight Hall is powered by the dynamo. With Moler are, left to right, Ellis L. Phillips '95, Professor E. L. Nichols, and Bancroft Ghirardi, a trustee. (See also page 6.)

lica of the medal (reproduced on the front cover) was loaned to the centennial committee of the School of Electrical Engineering by George F. Critchlow, a grandson of Moler, along with two historic photographs (reproduced on pages 6 and 45). The machine is still in storage at Cornell, apparently needing only a belt in order to power once again a lighting system. The story is included in Morris Bishop's *A History of Cornell,* published by the University in 1962:

The dynamo, shown at several world's fairs, was in active service at Rockefeller Hall at least till 1930, but has now become emeritus, performing only at high engineering festivals.

The electrical engineering centennial symposium on campus in the spring of 1985 is such a high engineering festival, and the dynamo will be there.



■ Professor Vladimir Karapetoff (on the faculty from 1905 to 1940) was quite an accomplished performer on the violin, viola, and cello. Once he recorded a full string quartet, playing all the instruments himself, by transcribing each part separately and synchronizing them. Today, with our versatile tape recorders, this achievement would not be remarkable, but then it was no small accomplishment. No one has come forward to say exactly how it was done—or how it sounded.

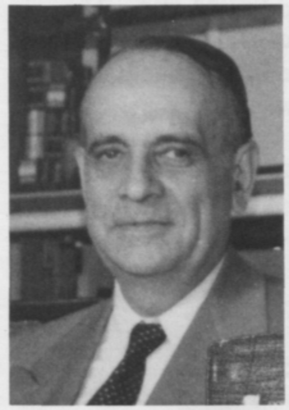
Karapetoff: the one-man quartet

■ Professor Michel Malti (on the faculty from 1923 to 1962) was famous for his lectures, which he wrote out in detailed outline on the blackboard while the students wrote furiously in a frantic effort to keep up. The board would soon be filled with the professor's clear but rather small script. Having worked his way to the extreme right, Malti would seize an eraser, briskly rub out everything, and start again at the left. The story goes that one day as the professor grabbed the eraser, a harried student cried out, "Hey, Prof, wait a minute!" And as Malti turned in surprise, eraser in mid-air, the student stood up with a flash camera and proceeded to photograph the board.

Malti

■ This story is probably apocryphal, but it has been told by many who allegedly observed the action: It seems that Professor William C. Ballard (on the faculty from 1912 to 1952), who assembled the vacuum-tube manufacturing laboratory that was in Franklin Hall and later in Phillips, developed such calluses on his fingers from working with the hot glass tubes that he could detect voltage differences simply by grasping the two terminals. At 220 volts he felt a slight tingling. At 110 volts he had to lick his fingers first in order to get enough sensation to declare, "Yep, that's hot!"

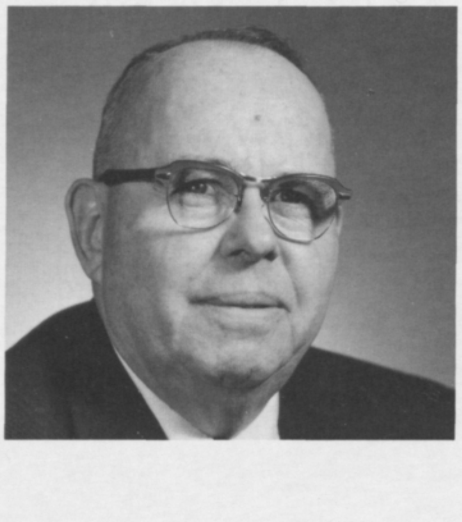
Ballard



■ The old Ithaca section of the American Institute of Electrical Engineers (AIEE), the predecessor of the present Institute of Electrical and Electronics Engineers (IEEE), included members from Binghamton, Corning, Elmira, and Ithaca. In late 1949, a meeting in Elmira attracted a particularly large audience to hear a lecture on a new xerographic copying process and to observe a demonstration model of the printing device. When the eight-foot-long machine was activated, it clanked along for a minute or so and then disgorged a smudged copy of the original. The general opinion was that this primitive Xerox copier wasn't likely to be reproduced in quantity.

■ One of the more arduous assignments in the old Rand Lab (and later in the Senior Power Lab in Phillips Hall) was the dreaded Experiment 17. This was a synchronous-machine exercise that involved synchronizing a small (5-kw) generator to the power-company line—an often traumatic experience. When it had been accomplished successfully, Professor Robert Osborn, who often supervised Experiment 17, would comment dryly, "Now you are sending power to the entire Northeast." The observation was hardly soothing to the participants' frazzled nerves.

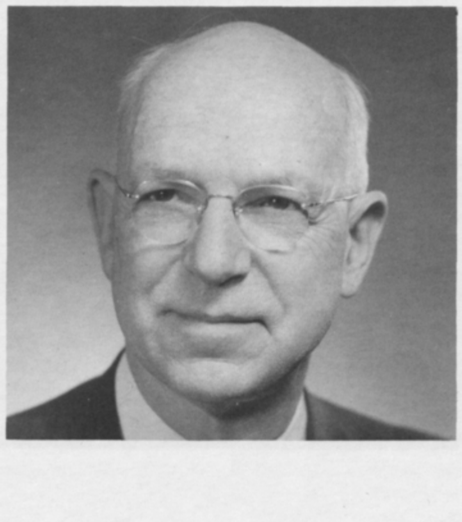
Osborn



■ Professor True McLean (on the faculty from 1923 to 1966) likes to tell this one: In the early days of solar astronomy research out at Tompkins County Airport, True was asked to set up a control circuit that would cause a large parabolic antenna to "track" the sun. A reference signal was needed, and the natural choice was the standard, readily available 60-Hz power frequency. Unfortunately, and probably to the discomfiture of the local power company, the frequency was found to drift. True had to devise a signal from a crystal-controlled oscillator at several hundred kHz in order to achieve satisfactory tracking.

■ A non-E.E. of years ago recalled his exposure to electrical engineering. "I don't remember the name of the professor," he wrote, "but he always tried to make the lecture interesting. Of course, I believed then and still do that his demonstrations were done by magic." One day, the story goes, the professor rigged up a photocell apparatus at the single entrance to the

McLean

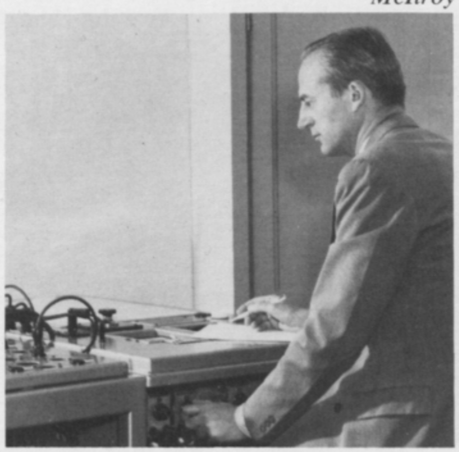


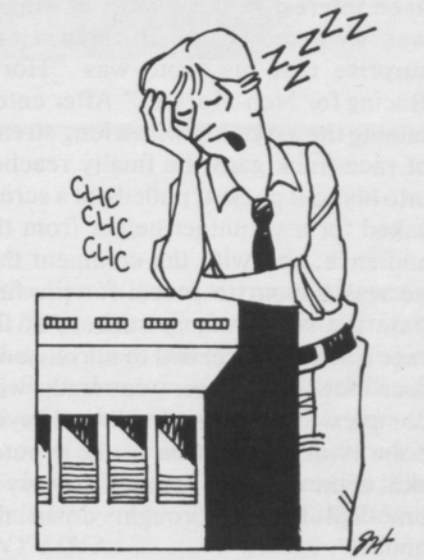
Franklin Hall lecture room so that as people came in the door they would interrupt a light beam and cause a doorbell on the lecture table to ring. Stragglers were loudly announced by the bell and then greeted by hoots from the students already present. "The magic part happened when the professor appeared in the doorway," our correspondent continued. "A huge fire bell, also on the lecture table, went off with a loud CLANG! CLANG! CLANG! *Numero Uno* had arrived!"

■ One day in 1953, after it had been announced that Ellis L. Phillips would finance construction of a new building for E.E., Professor Simpson Linke, who was a member of the new-building committee, happened to meet Dean S. C. Hollister in front of Sibley Hall. "Come with me to my office, Sam," said Holly with a somewhat conspiratorial air. "I want to show you something." They proceeded to the dean's office, where Holly ceremoniously pulled out the center drawer of his desk and extracted a long envelope, which he asked Sam to open. Inside was a check for one million dollars, made out to Cornell University and signed, "Ellis L. Phillips." After a moment of stunned silence, Sam asked, "Are you going to frame this, Dean Hollister?" "Hell no," said the dean. "I'm going to cash it!"

■ In the early fifties, Professor Malcolm McIlroy perfected the pipeline analyzer, an analog device to study fluid flow in the distribution networks of municipal and industrial water and natural-gas supply systems. Concerned about the possible impact of his "competition," the digital computer, he undertook to solve a typical fluid network on the only computer available on campus—an early IBM card-programmed calculator (CPC) used principally for accounting purposes. That machine, located in Rand Hall, was a mechanical monster that used punched cards for memory and featured a "high-speed" mechanical sorter noted for its fearsomely noisy operation. Mac reported that results from the CPC and from his analog device correlated well, although the CPC was terribly slow. "As much as I dislike to admit it," he is said to have remarked after the experiment, "I have no doubt that my pipeline analyzer will be completely obsolete in a few years."

McIlroy





■ The annual faculty-student banquet of the E.E. Delta Club was always an outstanding spring event. One year the after-dinner speaker was Professor William H. Erickson, who was then in charge of a "service" course he had titled "Electrical Engineering for Non-Electrical Engineers." Bill's keen interest in the "sport of kings" was well known, so it came as no surprise that his topic was "Horse Racing for Non-Horses." After entertaining the assembly with a long stream of race-track gags, he finally reached into his coat pocket, pulled out a scroll, asked for a volunteer helper from the audience, and with the comment that he was "about to reveal for the first time the secret of my success at the race track," proceeded to unroll about four feet of paper covered with complex-looking mathematical symbols. A demonstration of the reputed skill of the engineer in putting theory to practical use, it brought down the house.

■ One Tuesday afternoon in the fall of 1958, the speaker at the regular student-faculty E.E. colloquium was Professor William C. Gordon, who announced that he was going to talk about a brand-new idea. "Suppose you had a 1,000-foot-diameter spherical antenna connected to a powerful radar," he said, "with the antenna feed directed so as to send a signal to the planet Jupiter. At about noon you could turn on the radar transmitter long enough to send out some pulses, and then turn it off and go out for lunch. When you returned, you could turn on the radar receiver and be in time to catch the reflected pulse from Jupiter." This was how the E.E. faculty and students first heard about the idea for the famous Arecibo radar astronomy observatory.

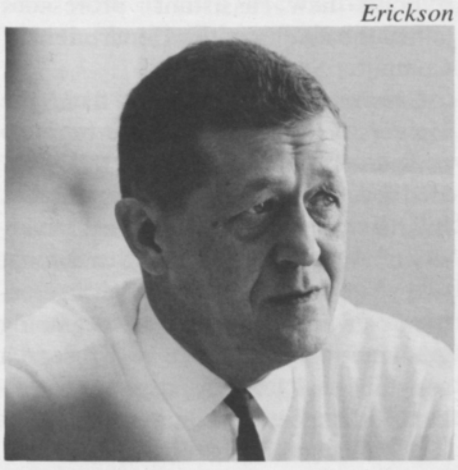
Gordon with an early model of Arecibo

■ For many years, a high point of the spring term was the annual Engineers' Day, when the various schools and departments in the College would compete in preparing elaborate exhibits for the entertainment and edification of visiting "artsies" and high-school students. E.E. often won first prize, possibly because it was easy for electrical engineers to set up a demonstration in which visitors could participate. A favorite stunt was to rig a d.c. generator with a crank and an accompanying dial calibrated as a "strength indicator." When a young man ap-

peared with his girlfriend, the E.E. "carnival barker" would urge the lady to try her luck with the crank. Invariably she would have no difficulty in registering a respectable score. When her companion took his turn, however, a well hidden E.E. accomplice would apply a dead short circuit across the terminals so that the fellow could barely make the needle move.

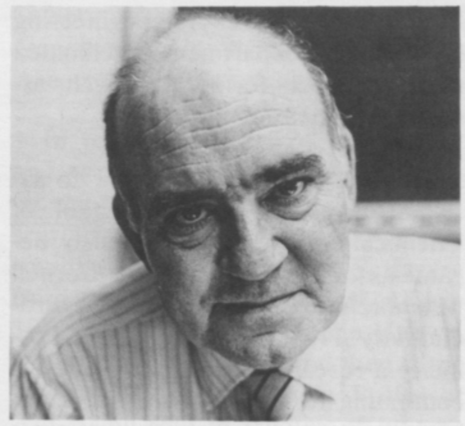
■ Two of the national meetings of the American Institute of Electrical Engineers (AIEE), those of 1935 and 1961, were held at Cornell. A significant feature of the 1961 meeting was the initiation of discussions that led to the merger of the AIEE with the Institute of Radio Engineers (IRE) to form the society that is now the IEEE. To Cornellians, though, that meeting is memorable for its recognition of Emeritus Professor Robert Chamberlain, then seventy-five years old, who had been chairman of the society's Ithaca section at the time of the 1935 general meeting. The 1961 meeting, which lasted five days and was attended by fifteen hundred delegates, is memorable too for its arrangements committee, which consisted of the entire E.E. faculty, impressed into service by William H. Erickson. "Skipper" Bill also impressed the University's worried conference director with the efficiency of his crew.

Erickson



■ Professor Joseph L. Rosson, perennial associate director of the School and adviser to hundreds of E.E.s through the years, had a reputation as a big tough guy with a heart of gold. A stern expression was expected, if not taken very seriously. On one occasion, though, an advisee was able to take a candid photo that showed Joe behind his desk, lighted cigarette in hand, with an uncharacteristic smile lighting his face. Some time later, on his birthday, Joe came to his office, early as usual, and found a copy of the *Cornell Daily Sun* on his desk. After perusing the first page, he opened the paper and was startled to find a full-page image of his smiling face with a huge caption: HAPPY BIRTHDAY PAPA JOE!

Rosson



Readers with other reminiscences of E.E. at Cornell are invited to send them to Professor Simpson Linke, who collected many of these and will earmark additional anecdotes for the School's newsletter. His address is School of Electrical Engineering, Cornell University, Phillips Hall, Ithaca, NY 14853.

REGISTER

Newcomers Augment Engineering Faculty

In the fall term several engineering schools and departments welcomed newcomers or former research associates to their faculties.

■ *Paulette Clancy* was named an assistant professor in the School of Chemical Engineering and also became associate director of the Cornell Manufacturing Engineering and Productivity Program (COMEPP). Formerly a research associate, Clancy is continuing her work on the application of computers to industrial processes; her research involves the development of methods for predicting complex thermodynamic properties of fluids and materials. She was educated in England, earning the B.Sc. degree at the University of London in 1974 and the D.Phil. at Oxford University in 1977. She first came to Cornell for a two-year assignment with Professor Keith Gubbins; after a year as a research fellow at British Telecom, she returned to Cornell in 1981. She is a member of the American Institute of Chemical Engineers, the American Chemical Society, and Sigma Xi.

■ In the School of Civil and Environmental Engineering, *Kenneth C. Hover* was appointed associate professor in structural engineering, and *William D. Philpot* was named assistant professor in environmental engineering.

Hover recently earned the Ph. D. in structural engineering at Cornell after ten years as a practicing engineer. With B.S.C.E. and M.S.C.E. degrees from the University of Cincinnati, he worked with the U.S. Army Corps of Engineers; at the Dugan and Meyers Construction Company and THP Ltd., Structural Engineers, in Cincinnati; and as village engineer in Mariemont, Ohio. At his undergraduate university he received the Dean Herman Schneider Award; the army awarded him a Commendation Medal; and as a teaching assistant at Cornell in 1983, he was elected Teacher of the Year in Civil Engineering. He is a member of the American Society of Civil Engineers, the American Concrete Institute, the American Society for Testing and Materials, the Post Tensioning Institute, and the National Association of Corrosion Engineers.

Philpot has also had previous experience at Cornell; he has been associated with the Remote Sensing Program as an assistant professor (1981-82) and research associate (1983-84). He earned the B.A. degree from New York University in 1969, the B.S. from the State University of New York at Stony Brook in 1973, and the M.S. and Ph. D. at the College of Marine Studies of the University of Delaware in 1977 and 1981, respectively. Before coming to Cornell, Philpot served as a research assistant at Delaware and as a research associate at the National Academy of Sciences, working with the Committee of Remote Sensing Programs for Earth Resources Surveys. His honors include several awards from the University of Delaware: one for professional development in marine science, and one for the best thesis in applied ocean science. He is a member of the Optical Society of America, the Society of Photo-Optical Instrumentation Engineers, the American Society of Photogrammetry, and Sigma Xi.

■ Four new assistant professors joined the faculty of the Department of Computer Science this fall.

Gianfranco Bilardi came from the University of Illinois, where he is to complete his doctoral studies this year. His area of concentration is theory. Bilardi was graduated from the University of Padova, Italy, in 1978 and spent two years there as a researcher in electrical engineering before beginning graduate study. He served as a research assistant and teaching assistant at Illinois and spent the summer of 1983 at IBM's Watson Research Center.

Alexandru Nicolau, a specialist in computer architecture and parallel computation, received the B.A. degree from Brandeis University in 1980 and did his graduate work at Yale University, earning the M.Phil. in 1982, the M.S. in 1983, and the Ph.D. in 1984. Before entering college, he served for three years as an electronics technician in the Israeli military forces. He is a member of the Association for Computing Machinery.

Jon Solworth, whose specialties are VLSI computer-aided design and architecture, was educated at New York University; he earned the B.A. degree in 1978 and the M.S. in 1981, and is scheduled to receive the Ph.D. this year. Currently he is an acting assistant professor.

Vijay Vazirani served as a research fellow at Harvard University after receiving the Ph.D. from the University of California at Berkeley in 1983; his thesis work was on the theory of algorithms and computational complexity. His undergraduate degree is from the Massachusetts Institute of Technology. His experience includes summer work at IBM, Hewlett-Packard, and the Jet Propulsion Laboratory.

■ After six years as an assistant professor in computer science at Cornell, *Franklin T. Luk* was appointed associate professor in the School of Electrical Engineering. His specialty field is numerical analysis, and he is associated with the Center for Applied Mathematics at Cornell. Luk received the B.S. degree from the California Institute of Technology in 1972 and studied at Stanford University for the M.S., granted in 1974, and the Ph.D. in 1978. In the summers of 1982 and 1983 he was a visiting fellow at the Australian National University.

S. Simon Wong was appointed an assistant professor in electrical engineering, beginning in the 1985 spring term. He holds B.E.E. and B.M.E. degrees from the University of Minnesota, and the M.S. and Ph.D. from the University of California at Berkeley. After receiving his master's degree, Wong worked at the National Semiconductor Corporation for two years before returning to Berkeley for his doctorate, granted in 1983. Since then he has been a member of the technical staff at the Hewlett-Packard Laboratories. His research centers on the technology of high-speed silicon integrated circuits.

Muawia Barazangi, who has been associated with the Department of Geological Sciences since 1972, has been named an adjunct professor and elected a member of the graduate Field of Geological Sciences. He retains his position as senior research associate in the Institute for the Study of the Continents (INSTOC). Barazangi received the B.S. degree from Damascus University, Syria, in 1965, the M.S. from the University of Minnesota in 1967, and the Ph.D. from Columbia University in 1971. During a leave in 1978-80, he served as associate professor and chairman of the Department of Geophysics at King Abdulaziz University, Jeddah, Saudi Arabia. Barazangi's research is focused on the seismotectonics of convergent plate boundaries. He is a member of the American Geophysical Union and the Seismological Society of America.

Richard W. Allmendinger, formerly a research associate, is now an assistant professor of geological sciences. A Cornell graduate of 1975, he earned the Ph.D. at Stanford University in 1979 and then returned to Cornell. His area of interest is structural geology and the tectonics of compressional and extensional forces. He has worked as a research geologist with the U.S. Geological Survey, the U.S. Geodynamics Committee, the Decade of North American Geology, and the Argentine and Chinese Lithosphere Programs. He is a member of the Geological Society of America, the American Geophysical Union, and the American Association of Petroleum Geologists.

■ In the Department of Theoretical and Appled Mechanics, *Fadil Santosa* moved from his appointment as a research associate to an assistant professorship. He received the B.S. degree from the University of New Mexico in 1976 and the Ph.D. from the University of Illinois in 1980, and then came to Cornell to work with Professor Yih-Hsing Pao in studies of inverse problems in wave propagation. He has been a member of Cornell's Center for Applied Mathematics since 1981.

■ Forty-five visiting faculty members at the College of Engineering during 1984-85 have come from eighteen countries: Argentina (1), Australia (1), China (9), Denmark (1), Greece (1), England (3), Finland (1), India (1), Israel (3), Japan (10), the Netherlands (1), Norway (1), Portugal (1), Taiwan (2), United States (6), Vanuatu (1), West Germany (1), and Yugoslavia (1).

Year Opens with Changes in Administration

■ The new half-time position of associate dean for computing is held by *Mark A. Turnquist*, an associate professor in the Department of Environmental Engineering. His specialty, transportation-system analysis and transportation economics, involves the use of computer-based mathematical models, and he has served as director of the computer facility in the School of Civil and Environmental Engineering.

Turnquist holds the B.S. degree from Michigan State University and the S.M. and Ph.D. from the Massachusetts Institute of Technology. Before coming to Cornell in 1979, he taught for four years at Northwestern University, where he was also affiliated with the Transportation Center. He has served as a consultant to federal agencies, local governments, mass-transit operators, and railroads. He is a member of the Transportation Research Board and the Operations Research Society of America.

■ The new director of the School of Electrical Engineering is *John A. Nation*, a specialist in plasma physics and high-energy electron and ion beams who has been a member of the faculty since 1965. At Cornell he has also served as associate director of the Laboratory of Plasma Studies.

Nation was educated at Imperial College, London, which awarded him the B.Sc. degree in 1957 and the Ph.D. in 1960. Before coming to Cornell, he worked at the Frascati center of the Comitato Nazionale per l'Energia Nucleare in Italy, and then in England at the Central Electricity Generating Board's research laboratories. He has served as a consultant to federal agencies, and government and industrial laboratories. He is a fellow of the American Physical Society and a senior member of the Institute of Electrical and Electronics Engineers.

As director, Nation succeeds Joseph M. Ballantyne, who became the University's vice-president for research and advanced studies.

■ In the Department of Agricultural Engineering, *Gerald E. Rehkugler* has become chairman, succeeding *Norman R. Scott*, named director for research at the College of Agriculture and Life Sciences.

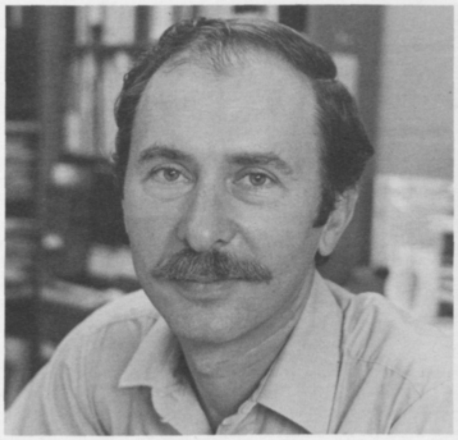
Turnquist

Rehkugler's specialties and research interests are the design of agricultural and food-processing machinery, food engineering, solar refrigeration, and vehicle dynamics. He first joined the agricultural engineering faculty in 1958 after receiving the B.S. and M.S. degrees from Cornell. Later he earned the Ph.D. at Iowa State University, was a visiting professor at Michigan State University, and conducted research at the Cornell Animal Science Teaching and Research Center while on sabbatical leave.

■ *Peter Gergely,* chairman of the Department of Structural Engineering, has been named director of the School of Civil and Environmental Engineering. He will continue as department chairman.

In addition to his administrative and teaching activities, Gergely conducts an active program of research. His specialty areas include structural mechanics, shells, dynamics, earthquake

Gergely



Yohn

engineering, materials, and reinforced concrete.

He began his undergraduate education at the Technical University of Budapest, received the B.Eng. degree from McGill University, and did his graduate work at the University of Illinois. He came to Cornell in 1963.

His experience includes employment as a draftsman and structural engineer, and he has spent leaves at industrial and university laboratories in the United States, Hungary, and Canada. He is a fellow of the American Society of Civil Engineers (ASCE) and the American Concrete Institute (ACI), and has received four national awards, including the ACI's 1982 Distinguished Service Award.

■ *Charles P. Yohn*, a 1950 Cornell graduate in mechanical engineering, was named director of corporate relations for the College. Yohn comes to Cornell from the Aluminum Company of American (ALCOA), where he was manager of technical planning. He joined ALCOA immediately after graduation, and in the ensuing thirty-four years held a broad range of engineering and managerial assignments.

Yohn's early engineering work at ALCOA involved the development of new slitting techniques and equipment in the foil division; later he was instrumental in establishing the company's precision forging operation. He was also responsible for the installation of ALCOA's first CAD/CAM system for designing and manufacturing forging dies. In recent years he was heavily involved in the effort to identify and plan for technologies relevant to the company's future.

Yohn is a graduate of the Case Western Reserve University Advanced Management Program. He is a member of the Institute of Industrial Engineers, the Society of Manufacturing Engineers, Sigma Xi, and Tau Beta Pi.

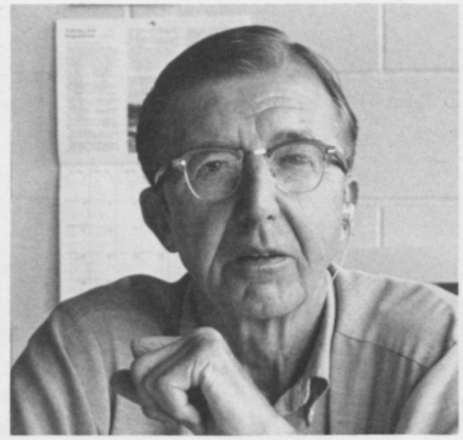
■ Other staff positions recently filled are in alumni affairs, undergraduate admission, and placement.

Mary T. Orr was named to the new position of alumni assistant in the College's Office of Development and Alumni Affairs. She works closely with Mary Berens, the director, in administering the campus-based support for the Cornell Society of Engineers, an alumni organization. The position is funded jointly by the College and the Society. Orr has had previous Cornell experience in the University's Development Office.

In a reorganization of the Office of Admissions and Undergraduate Affairs, *John Belina* has become assistant dean for admissions and records, and *Ron Simmons* has beome assistant dean for advising, counseling, and minority programs. Two admissions and advising specialists, *Maureen O'Neill Fellows* and *Richard W. Hale*, have joined the staff. Fellows recently earned the Cornell M.S. degree in human factors engineering (centered in the College of Human Ecology). She has done academic and personal counseling in work with the American Society for Engineering Education. Hale holds a master's degree in aerospace engineering from Cornell and has had extensive experience in technical areas, most recently in the management of information systems.

The new coordinator of engineering placement is *Mark Savage*, who came to Cornell from Salem College in West Virginia, where he was director of career planning and placement. Savage received the B.A. degree in English and psychology from Ball State University, Indiana, in 1975 and the M.S. in counseling and psychological services from the State University of New York at Oswego in 1976. His experience includes five years at Ohio University in the residence hall system and in career advising.

Shepherd



Cornell Engineering Professors and Graduates Receive Honors

■ Two Cornell faculty members in mechanical and aerospace engineering, *Dennis G. Shepherd* and *Kuo-King Wang,* have been named fellows of the American Society of Mechanical Engineers (ASME). Also named a fellow is an alumnus, *Marcus N. Bressler,* a staff specialist with the Nuclear Engineering Branch of the Tennessee Valley Authority (TVA), who received a baccalaureate degree in mechanical engineering in 1952.

Shepherd, who is John Edson Sweet Professor of Engineering, emeritus, was recognized for a "distinguished series of textbooks on fluid mechanics, turbomachinery, and propulsion," for his contribution of "important experimental knowledge of fin-tube heat transfer," and for his "influential appraisals of the prospects for wind power." He came to Cornell in 1948 after fourteen years in industrial research and development in England and Canada, where he participated in early work on turbojet engines and gas turbines. He received his early education in England and attended the University of Michigan, where he earned baccalaureate degrees in engineering mathematics and engineering physics.

At Cornell he served as head of the Department of Thermal Engineering and later, the Sibley School of Mechanical Engineering (now Mechanical and Aerospace Engineering). He twice received the annual Excellence in Engineering Teaching Award at the College of Engineering.

Other honors have included the Worcester Reed Warner Medal of the ASME and a Guggenheim fellowship. He spent leaves at Imperial College, London, as a senior visiting fellow of the Organization for European Economic Cooperation, and at the Technische Hogeschool in Delft, The Netherlands, as a visiting professor. In the ASME he is a member of the turbomachinery and combustion committees of the Gas Turbine Division, and a member of the executive committee of the Southern Tier section. He belongs also to the Institution of Mechanical Engineers (in England), the Combustion Institute, and the American Wind Energy Association.

Wang, a member of the Cornell faculty since 1970, was cited for his initiation of a "manufacturing engineering program which has received national recognition" (COMEPP, the Cornell Program in Manufacturing Engineering and Productivity), and for his innovative work as director of the interdisciplinary Cornell Injection Molding Program (CIMP).

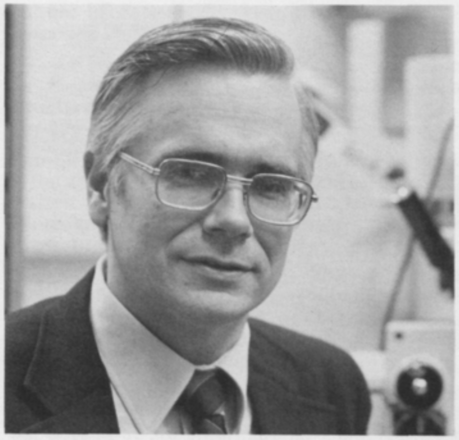
He began his university education in China, where he earned the B.S.M.E. degree at National Central University in 1947. After graduating, he worked at the Ingalls-Taiwan Shipbuiding Corporation and then came to the United States for graduate education. He earned the Ph.D. at the University of Wisconsin and taught there for two years before coming to Cornell.

Previous honors he has received are the Blackall Machine Tool and Gage Award from the ASME and the Adams Memorial Membership Award given on an international basis by the American Welding Society. In 1977 he received the first TRW fellowship in manufacturing engineering.

In the ASME Wang is active in the Production Engineering Division. He

Wang

Kramer



is a member also of the American Society for Metals, the Society of Plastics Engineers, the Society of Manufacturing Engineers, the American Welding Society, and the Numerical Control Society.

Bressler joined the Babcock and Wilcox Company after graduating from Cornell, and studied at the Case Institute of Technology for the M.S. degree, granted in 1960. Later he was an applications and design engineer for Gulf and Western's Lenape Forge Company in Philadelphia and in 1970 transferred to Gulf and Western's Taylor Forge Company in Chicago, where he was manager of product design and development. He joined the TVA in 1971 and rose to staff specialist, codes and materials, in 1979.

Bressler has been active in the ASME and in 1980 received the Century Medallion of the East Tennessee Section for his work in codes and standards. He is also a member of the American Society for Testing and Materials, the American Society for Metals, the Knoxville Technical Society, and the Cornell Society of Engineers.

■ *Edward J. Kramer,* professor of materials science and engineering, is one of two scientists who have been awarded the 1985 High Polymer Physics Prize of the American Physical Society (APS). The award, considered the most prestigious in the field of polymer physics, is sponsored by the Ford Motor Company and is accompanied by a $3,000 prize. The co-winner is Roger P. Kambour of the General Electric Research and Development Center in Schenectady.

The recipients were recognized for "outstanding contributions to the understanding of crazing in polymers." Kambour showed that crazes—microscopic defects that form just before a polymer glass fractures—consist of load-bearing filaments of aligned molecules. Kramer and his research group discovered the mechanisms by which these crazes form. The work has led to the development of ways to make plastic tougher.

Kramer, a Cornell baccalaureate graduate, joined the faculty in 1967 after earning the Ph.D. at Carnegie-Mellon University and serving as a postdoctoral fellow at Oxford University. Active in Cornell's Materials Science Center, he has been a visiting scientist at Argonne National Laboratory, a Karl Friedrich Gauss Professor at the Akademie der Wissenschaften in West Germany, and a visiting professor at the Ecole Polytechnique Fédérale de Lausanne in Switzerland. He is a fellow of the APS and a member of the American Chemical Society, the Society of Plastics Engineers, and the American Association for the Advancement of Science.

Kramer is the fourth scientist affiliated with Cornell who has won the APS High Polymer Physics Prize. Two of these previous recipients are Nobel laureates: the late Peter J. W. Debye, a member of the University's chemistry faculty from 1940 to 1966, and Paul Flory, a member of the chemistry faculty from 1948 to 1956. The other is Pierre-Gilles deGennes, who was an Andrew D. White Professor-at-Large at Cornell from 1977 to 1983. The work of deGennes that brought him the APS prize was integral to Kramer's prizewinning discovery.

■ A Cornell engineering physics graduate, *Arthur T. Winfree,* received an unsolicited award from the MacArthur Foundation this fall. MacArthur awards provide up to $300,000 over five years to facilitate creative work.

Winfree, who earned the Cornell B.S. degree in 1965, is now a professor of biological science at Purdue University. His research in mathematical biology has focused on the analysis of oscillations in biological systems. He is the author of *The Geometry of Biological Time* (1980).

FACULTY PUBLICATIONS

Current research activities at the Cornell University College of Engineering are represented by the following publications and conference papers that appeared or were presented during the three-month period July through September, 1984. (Earlier entries omitted from previous Quarterly *listings are included here with the year of publication in parentheses.) The names of Cornell personnel are in italics.*

■ AGRICULTURAL ENGINEERING

Irwin, L. H. 1984. Critical concerns of low-volume road agencies in the 1980s. *Transportation Research Record* 898:1–10.

Loehr, R. C. 1984. EPA's engineering and control technology program. *Environmental Science and Technology* 18:171A.

Loehr, R. C., J. H. Martin, Jr., and *E. F. Neuhauser.* 1984. Disposal of oily wastes by land treatment. In *Proceedings, 38th Annual Purdue Industrial Waste Conference,* pp. 1–12. Ann Arbor, MI: Ann Arbor Science.

Naylor, L. M., and *N. I. Mondy.* 1984. Metals and PCBs in potatoes grown in sludge amended soils. Paper no. 84–211, read at North Atlantic Regional Meeting, American Society of Agricultural Engineers, 12–15 August 1984, in Orono, ME.

Neuhauser, E. F., R. C. Loehr, and *M. R. Malecki.* 1984. Methods for evaluating the biological impact of potentially toxic waste to soils. Paper read at 4th Symposium on Hazardous and Industrial Waste Testing, American Society for Testing and Materials, 2–4 May 1984, in Arlington, VA.

Pitt, R. E. 1984. Stress-strain and failure characteristics of potato tissue under cyclic loading. *Journal of Texture Studies* 15:131–55.

■ APPLIED AND ENGINEERING PHYSICS

Cool, T. A. 1984*a*. Detection of flame radicals by multiple photon ionization. Paper read at annual meeting of American Chemical Society, 26–31 August 1984, in Philadelphia, PA.

———. 1984*b*. Lasers for ultrasensitive detection of trace chemicals. *Engineering: Cornell Quarterly* 19(1):7–11.

———. (1984*c*.) Quantitative measurement of NO density by resonance three-photon ionization. *Applied Optics* 23:1559–72.

———. (1984*d*.) The use of resonance enhanced multiple photon ionization for quantitative measurements of combustion radical densities. Paper read at 17th AIAA Fluid Dynamics, Plasma Dynamics, and Lasers Conference, 25–27 June 1984, in Snomass, CO.

———. 1984*e*. The use of resonance enhanced photon ionization for the detection of flame radicals. Paper read at 11th Annual Meeting of Federation of Analytical Chemistry and Spectroscopy Societies, 16–21 September 1984, in Philadelphia, PA.

———. (1984*f*.) Use of laser techniques for detecting flame radicals. Paper read at Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, 5–9 March 1984, in Atlantic City, NJ.

Cool, T. A., and *P. J. H. Tjossem.* 1984*a*. Direct observations of chemi-ionization in hydrocarbon flames enhanced by laser-excited $CH^*(A^2\Delta)$ and $CH^*(B^2\Sigma^-)$. Paper read at 20th International Symposium on Combustion, 12–17 August 1984, in Ann Arbor, MI.

———. 1984*b*. Direct observations of chemi-ionization in hydrocarbon flames initiated by laser-excited $CH^*(B^2\Sigma^-)$ and $CH^*(A^2\Delta)$. Paper read at annual meeting of American Chemical Society, 26–31 August 1984, in Philadelphia, PA.

Erlandson, A. C., and *T. A. Cool.* 1984. Metal hydride photodissociation lasers: Laser operation for Al and In photofragments. *Journal of Applied Physics* 56:1325–28.

Lehr, W., J. Machta, and *M. Nelkin.* 1984. Current noise and long time tails in biased disordered random walks. *Journal of Statistical Physics* 36:15–29.

Tjossem, P. J. H., and *T. A. Cool.* (1983.) Detection of atomic hydrogen in flames by resonance four-photon ionization at 365 nm. *Chemical Physics Letters* 100:479–83.

———. 1984. Species density measurements with the REMPI method: The detection of CO and C_2O in a methane/oxygen flame. Paper read at 20th International Symposium on Combustion, 12–17 August 1984, in Ann Arbor, MI.

■ CHEMICAL ENGINEERING

Anderson, C. C., P. D. Krasicky, F. Rodriguez, Y. M. N. Namasté, and *S. K. Obendorf.* 1984. Chain-scissioning yields of methacrylate copolymers under electron beam radiation. In *Polymers in electronics,* ed. T. Davidson, pp. 119–27. Washington, DC: American Chemical Society.

Calado, J. C. G. 1984. Thermodynamics of simple fluids: Planetary applications. Paper read at 7th Annual Meeting, Portuguese Chemical Society, 9–13 July 1984, in Lisbon, Portugal.

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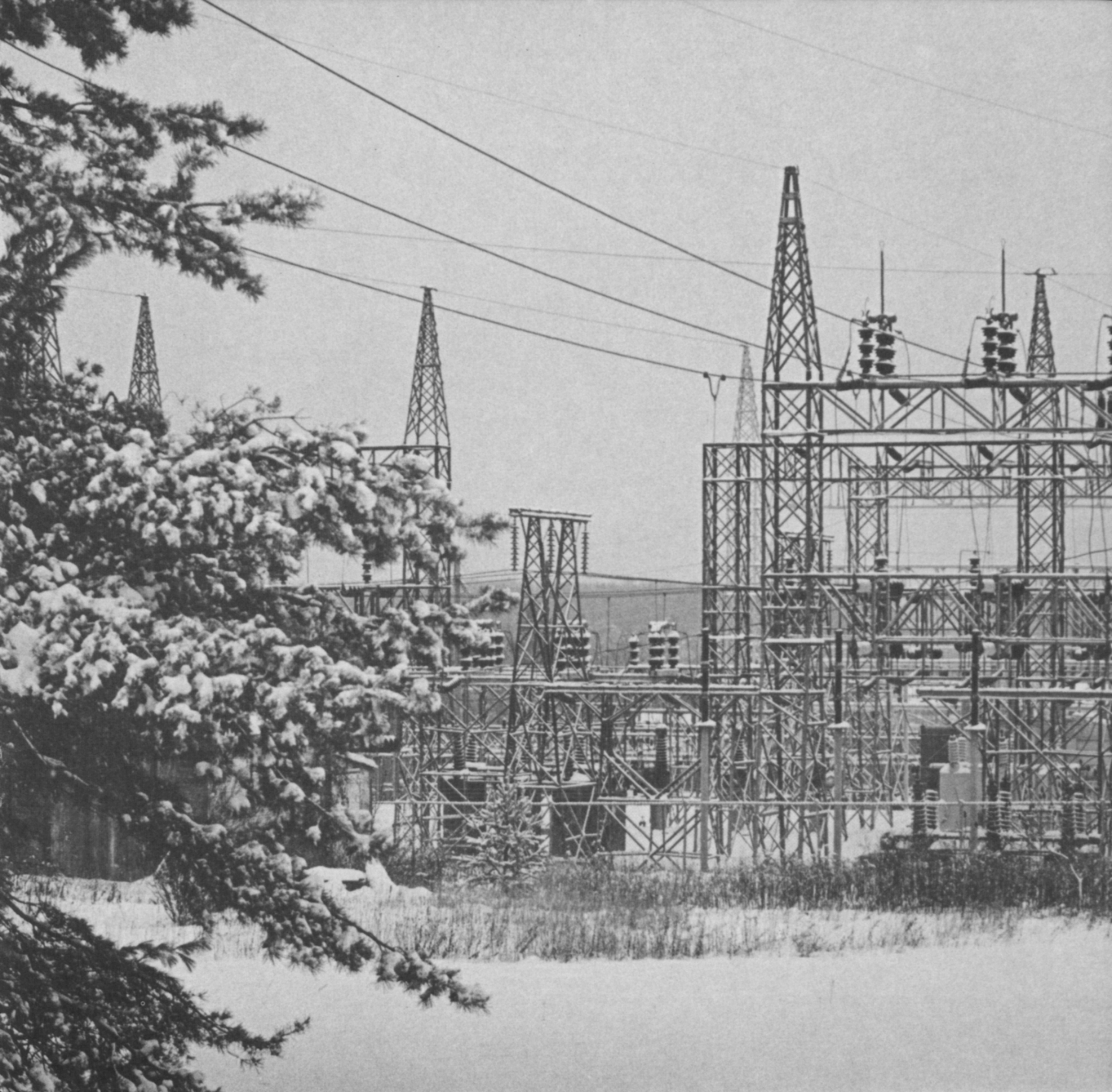

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