

History of the Department of Electrical Engineering

Professor Henry Smith Carhart (Wesleyan '69, Sc.D. hon. Northwestern '12, LL.D. Michigan '12), assisted by Joseph E. Putnam, in 1888-89 offered the first course in dynamoelectric machinery as a course in physics. Thus began the instruction which resulted in the establishment of a separate Department of Electrical Engineering. The work was given in the east basement room of the Physics Laboratory with meager equipment, consisting of a twenty-five-horsepower high-speed steam engine driving a line shaft, an Edison dynamo of five-kilowatt capacity, a ten-arc Brush dynamo with arc lamps, a five-horsepower constant-potential motor, and a Brackett cradle dynamometer. Adjacent to the laboratory were a small photometric room and a battery room containing a thirty-one-cell storage battery. The first three degrees were granted in 1890 to Winthrop E. Gastman, William D. Ball, and Louis C. Hill.

In 1889 George Washington Patterson (Yale '84, Massachusetts Institute of Technology '87, Ph.D. Munich '99) was appointed Instructor in Electrical Engineering, and a four-hour course in distribution and photometry was given which, with the four hours of dynamo-electric machinery, made eight hours available in electrical engineering. By 1891-92 a course in alternating current transformers had been added, the text being J. A. Fleming's *The Alternate Current Transformer*. In 1893-94 the course in distribution of electrical currents and photometry was divided into two courses, both of which were taught by Patterson, and the following year a course in the design of electrical machinery was introduced by Carhart. This was apparently the first attempt to add what might be called professional instruction in contrast to the other courses, which were

really in physics.

A radical change took place in 1895-96, when the work in electrical engineering was separated from the work in physics, marking the recognition of the Department of Electrical Engineering. The curriculum remained the same, with the addition of a number of courses such as Electrical Measurements and Primary Batteries. In the following year a course in alternating current apparatus, taught by Carhart, was offered for the first time. Putnam had resigned in 1889, and in 1897-98 the staff, enlarged by the appointment of an instructor, Carroll Dunham Jones ('93e [E.E.], E.E. '97), consisted of Carhart of the Physics Department, Patterson, and Jones, who was replaced by Benjamin Franklin Bailey ('98e [E.E.], Ph.D. '07) in 1901.

During the next five years the department had a steady growth. Patterson and Bailey, who comprised the staff, were assisted by members of the Physics Department. In 1904 about half of the present West Engineering Building was completed, and the department moved into the south end of the basement of the new building. In 1905 Patterson was appointed Professor of Electrical Engineering, and an instructor, Ernest Steck ('01e [E.E.]), was added. He was succeeded in the following year by Lyman Foote Morehouse ('97e [E.E.], A.M. '04).

In the period 1905-15, with Patterson as head of the department, enrollment increased, new equipment was added, and the staff grew from four to eight members, with two assistants. Among those who deserve mention is Henry Harold Higbie (Columbia '04e [E.E.]), who was transferred from Mechanical Engineering to Electrical Engineering, and to whom credit is due for the development of the work in illumination. Because of his efforts Michigan is one of the

leading universities in the United States for study in this field. Carl Leonard de Muralt (Zurich '95e [E.E.]) served from 1907 until 1913. Alfred Henry Lovell ('09e [E.E.], M.S.E. '14) was appointed Instructor in Electrical Engineering in 1910. He became Professor in 1919 and chairman of the department in 1945. He was also Assistant Dean of the College of Engineering from 1930 to 1944. His interest and experience have been principally in power-plant work, and he is responsible for the group of courses relating to power-plant design and transmission, which place special emphasis upon the economic aspects of power generation and utilization.

The number of courses offered during the decade 1905-15 grew from sixteen to thirty-two. Part of this growth was caused by the introduction of required courses in electric communications work, which was at first under the direction of Morehouse. His success in this field resulted in his resignation in 1910 to accept a position with the American Telephone and Telegraph Company. The work was carried on by Ralzemond Drake Parker ('05e [E.E.], M.S. '06) until 1915, when he joined the same company. Harry Stevenson Sheppard ('12e [E.E.], M.S.E. '19) followed and was succeeded in turn by Porter Henderson Evans ('14e [E.E.], M.S. '20), Erwin Ernest Dreese ('20e [E.E.], E.E. '29), William Littell Everitt (Cornell '22e [E.E.], Ph.D. Ohio State '33), and Arlen Roosevelt Hellwarth ('25e [E.E.], M.S. '36).

The dynamo laboratories and offices of the department were moved to the north end of the West Engineering Building when it was completed in 1909. The communications laboratories were left in the south end, and a little later the illumination laboratories were moved to the attic.

In 1915 John Castlereagh Parker ('01, A.M. '02, E.E. '04, D. Eng. hon.

'40) was appointed chairman of the department, and Professor Patterson became chairman of the Department of Engineering Mechanics. Parker had a background of extensive power system experience as well as a decided inclination toward scholarly pursuits. He remained with the University until 1922, during a period of rapid expansion. The staff at that time numbered fourteen men, in addition to several teaching fellows and student assistants.

Arthur Dearth Moore (Carnegie Institute of Technology '15e [E.E.], M.S. Michigan '22) was appointed Instructor in 1916; he became Professor of Electrical Engineering in 1931. His teaching interest has been largely in electrical design and in problems of heat transfer. He has taken a special interest in student personnel problems, and from 1928 to 1952 he served as Head Mentor in the College.

Both Joseph Henderson Cannon (Purdue '07e [E.E.]), who became Associate Professor in 1917 and Professor in 1920, and Stephen Stanley Attwood ('18, M.S. '23), who joined the staff as Instructor in 1920 and was promoted to Professor in 1938, have devoted themselves largely to the theoretical phases of electrical engineering. Melville Bigham Stout ('20e [E.E.], M.S. '24), appointed Instructor in 1922 and Professor in 1943, has done notable work in mathematics and in the theory of electrical rectification. He has been responsible both for the development of the courses in instrumentation and for the associated standards laboratories.

Others who served during this period include Ward Follet Davidson ('13e, M.S. '20), James Ferdinand Fairman ('18e [E.E.], M.S. '21), and Edwin Blythe Stason (Wisconsin '13, Massachusetts Institute of Technology '16e, J.D. Michigan '22).

Under Parker radical changes took place in the curriculum and in the general philosophy of the department. It was evident to the staff that electrical engineering was "growing up." In the early days it was possible in four years to give the student a fairly comprehensive picture of the entire field of electrical engineering, including details of practice. The theory of electrical engineering advanced rapidly, however, and books and articles in the field became increasingly mathematical in character. The engineer was expected to know much more theory, and at the same time the scope of the applications of electricity expanded. Radio became important, and with it electronics as a science was developed. Obviously, it was no longer possible to cover the entire field as had been done in the past. One possible method was to specialize. Thus, a student might graduate with considerable knowledge of detailed telephone practice, but with little or no familiarity with dynamos or motors. Such a solution was never seriously considered; it was felt that specialization should come after graduation, not before. This decision was supported by the large electrical companies, which offered the graduate opportunity to discover his special interests and to learn the practical applications of electricity under the best possible conditions. Accordingly, the practical and more or less descriptive courses were discontinued, which reduced the thirty-two courses given in 1915 to twenty-three in 1919. New work of a theoretical nature was introduced, however, and course offerings gradually increased. Throughout this period there was a general stiffening of requirements.

In 1922 Parker resigned and was succeeded by Bailey, who was chairman from 1925 to 1944. On Bailey's retirement, Lovell was chairman until 1953, when he was succeeded by Attwood. After 1945 the department experienced the tremendous expansion of the postwar era caused by the G.I. enrollment. In 1947 the electrical

engineering undergraduates numbered more than 700 and the graduate students 100. Correspondingly, the faculty had increased to twenty-eight members: eight professors, three associate professors, one assistant professor, one lecturer, and fifteen instructors. The department was moved to the new south wing, which was added to the East Engineering Building in 1947, and thus had an opportunity to arrange for efficient operation. The basement was occupied by the power substation, the dynamo and photometry laboratories, and the instrument shop. Offices and laboratories were on the second floor, and the third and fourth floors were allotted to communications and electronics. This has greatly facilitated the work of the department.

Electronics has become of great practical importance in electrical engineering, both in communications and in industrial power. The increasing use of mercury vapor lamps, neon and fluorescent tubes in illumination, the tremendous growth of radio and television, and the introduction of the photoelectric cell have all contributed to this result. Some instruction in electronics had been available since 1915 in connection with the study of vacuum tubes in radio and in certain courses in physics. In 1930 electronics was offered as an elective, and in 1931 it was made a requirement, the first such requirement by an engineering school in this country. This was followed by instruction in industrial electronics, networks, gaseous-conducting electronic apparatus, theory of high-vacuum electron tubes, and microwave electron tubes.

The increased offerings of the department necessitated a proportionate increase in the size of the teaching staff. Professor Lewis Nelson Holland ('23e [E.E.], M.S. '26) joined the department in 1924 and has contributed much to the development of both the graduate and undergraduate work in radio and in associated phases

of the communications curriculum.

William Gould Dow (Minnesota '16e, M.S.E. Michigan '29) came in 1926 as Instructor in electronics and became Professor in 1945. His pioneer work in vacuum-tube design principles and his authoritative text on the subject have given the University of Michigan a foremost place in electronics. The curriculum is rich in the treatment of those fundamentals which control the functioning of electric devices.

Engineers have become increasingly aware of the importance of economics in engineering, and the early requirement of six hours in that field has been followed by economic analysis of the designs considered in the courses on power generation and transmission. The vast size of present electric systems and their interconnections have called for engineering advances in the operational calculus, alternating-current vector algebra, symmetrical components, and power system stability.

In 1942 two important additions were made to the staff: Assistant Professor Jack Fribley Cline ('38e [E.E.], Ph.D. '50), appointed to help with work in communications, and Associate Professor Henry Jacob Gomberg ('41e [E.E.], Ph.D. '51). During World War II Gomberg was commissioned to design and install a radio research laboratory at the University of Iowa for the Navy. In addition to his work in the Electrical Engineering Department, he has served as laboratory director for the radioactive materials on research projects of the American Cancer Society and is Research Associate and Assistant Director of the Michigan Memorial-Phoenix Project. Gomberg also developed the laboratory and prepared the first course offered by the department in nuclear engineering. In 1943 Professor James Sherman Gault ('21e [E.E.], M.S. '24) began research and development in the

theory of servomechanism and built up a laboratory in order to teach the subject as it relates to gun and turret control to classes of servicemen. This field has continually expanded, and control systems using electric, hydraulic, and pneumatic elements have been devised to regulate and govern the flow of energy. Assistant Professor Kazda collaborated in the work and has continued it since Professor Gault's death in 1951.

In 1946 three new members were added to the staff: John Joseph Carey (Massachusetts Institute of Technology '34e [E.E.]) was appointed Assistant Professor in the power and machinery curriculum, and Louis Frank Kazda (Cincinnati '40e [E.E.], M.S. *ibid.* '45) and Thomas Edwin Talpey (Cornell '46e [E.E.], M.S.E. Michigan '48) joined the department to help with the work in communications and electronics. Professor Edwin Richard Martin (Iowa State '11e, E.E. *ibid.* '17) came in 1947 to assist with the courses in machine design, Assistant Professor Walter Alfred Hedrich ('19e [E.E.], M.S. Michigan State '32) was appointed to help with the work in magnetic fields and illumination, and Richard Kemp Brown ('40e [E.E.], Ph.D. '52) was added to the staff in communications. Four men were appointed in 1948 to teach some of the more basic theoretical courses in electronics: Melvin Burtus Folkert ('47e [E.E.], M.S.E. '48), Phil H. Rogers (Texas '44, M.S. *ibid.* '47), Gunnar Hok (E.E. Royal Institute of Technology, Stockholm '26), and William Kerr (Tennessee '42e, M.S. *ibid.* '47). In the same year Kenneth Arnold Stone ('49e [E.E.], M.S.E. '52) and in the following year Joseph Aubrey Boyd (Kentucky '47e, M.S.E. *ibid.* '49) also became staff members. Associate Professor Alan Breck Macnee (Massachusetts Institute of Technology '43, Sc.D. *ibid.* '48), who established the courses in network synthesis, came to the University in 1950. Assistant Professor Norman Ross Scott (Massachusetts Institute of Technology '41, Ph.D. Illinois '50) was

appointed in 1951 and began a computer course, and in 1952 Professor Joseph Galluchat Tarboux (Clemson '18e [E.E.], E.E. Cornell '21, Ph.D. *ibid.* '37) joined the staff in power and machinery.

The subject of illumination and photometry, which has always been important in electrical engineering at Michigan, was a requirement in the first curriculum of 1889, with Patterson and Carhart as instructors. Higbie followed in 1913 and expanded the instruction for students in architecture and for those doing graduate work. In 1929 he offered a graduate course, *Natural Lighting of Buildings*, based on his extensive research on daylighting of interiors. Since his death in 1947 the instruction and research in lighting have been directed by Associate Professor Hempstead Stratton Bull (Lehigh '19e, M.S. Michigan '26) and Assistant Professor Hedrich.

In recent years the great increase in the number of graduate students reflects a growing conviction on the part of both the graduating engineer and the employer that four years is too short a time in which to master the fundamentals of electrical engineering. In general, a man does not return to receive specific instruction in the details of some particular branch, but rather to broaden and strengthen his foundation in mathematics and physics as applied to electrical engineering problems and to acquire some familiarity with methods of research. Staff members are encouraged and expected to participate in graduate work with the expectation that each will contribute something in his special field.

Research. — In the Department of Electrical Engineering research may be considered in three more or less distinct periods. Before the middle 1920's it was largely carried out on an individual basis by faculty members assisted by advanced students. The establishment of

the Department of Engineering Research (now Engineering Research Institute) in 1920 made it convenient to carry on industrially sponsored group investigation under faculty direction and with substantial employment of part-time students within the University laboratories and under conditions permitting broad use of the scientific resources of the University. During the third period, from the middle 1940's to the present time, a large volume of government-sponsored work, particularly in the electronics field, has been added to the industrially sponsored research. Comparable to this in importance have been the contributions made by the graduate student theses. The increased resources of the University resulting from sponsored research programs made possible a major expansion in thesis work.

The year 1875 marked the beginning of important research in electrical engineering at the University. In that year John Williams Langley (Harvard '61, M.D. hon. Michigan '77, Ph.D. hon. *ibid.* '92) met Charles Francis Brush ('69, Sc.D. hon. '12, LL.D. Kenyon '03), and their discussion of arc lamp generators resulted in independent studies of the problem. Soon each had built a successful arc lamp generator of the series type, both of which were far superior to other machines then in use. Brush's outstanding work, however, was in the design of an automatic device for advancing the arc lamp carbons as they were consumed.

In the period 1880-1900 frequent references were made to the work of Carhart in electrochemistry and to that of Patterson in the field of electrical measurements. Patterson's work in the measurement of insulation resistance was particularly notable. Others of this period who deserve mention are Frank Caspar Wagner (A.M. '84, '85e [Mech.E.]) for his mathematical analysis of motor design, Edwin

Henry Cheney ('92e [E.E.]) for a study of temperature rise in copper conductors, Eleazer Darrow ('92e [E.E.]) for his work on the economics of a double trolley railway system, Charles Gillman Atkins ('93e [E.E.]) and Edward Dana Wickes ('93e [E.E.]) for their study of the measurement of power in alternating current circuits, and Sergius Paul Grace ('96e [E.E.], E.E. '04, D.Eng. hon. '32) for his study of the fundamental characteristics of telephone circuits.

From 1900 to 1910 Ray Philip Jackson ('02e [E.E.]), Edward August Weiland ('04e [E.E.]), and Oswald William Visscher (Hope '01, Michigan '02, *ibid.* '04e [E.E.]) studied the properties of aluminum valve rectifiers. Harold Gillespie Bandfield ('05e [E.E.]) investigated the efficiency of charging batteries from three-phase alternating current through a rectifier, and Adolphus Mansfield Dudley ('02e [E.E.], E.E. '31, D.Eng. hon. '39) made elaborate studies of induction motors.

Among many research projects carried out by Bailey since 1900, the most outstanding have been a study of the slip of an induction motor by the stroboscopic method, the advantages of rheostatic starters for induction motors, and a study of magnetos, ignition systems, and starting equipment for automobiles. In the middle 1920's his investigation of fractional horsepower motors (single-phase) led to the development of condenser starting of single-phase motors and to a new type of electrolytic condenser.

Since 1924 Gault made important contributions in alternating-current machinery, particularly in work on "Rotor Bar Current in Squirrel-Cage Induction Motors," published in 1941. He made important consulting and engineering design and development contributions in servomechanisms and in the electric utilities field, particularly in

checking the electrical equipment design of the Detroit and Windsor Tunnel and the design and layout of two hydroelectric stations.

Parker, in the period 1915 to 1922, obtained important results in his work on the economic theory of engineering design and in the processes for determining obsolescence. Lovell continued and enlarged this program by analyzing the operating costs and the rate of growth of maintenance and replacement expense for numerous public utilities. More recently Carey has carried on research activity relative to stability problems of power systems.

From 1928 to 1932 the National Electric Light Association sponsored a major group research relative to wind-produced stresses in wood pole lines and the pattern of wind gusts, which involved extensive instrument design, field operations, and voluminous data reduction. Stout, Gault, and Dow made major contributions respectively to these studies. The results of this work appeared in a research bulletin, "Loading and Strength of Wood Pole Lines," by Sherlock, Stout, Dow, Gault, and Swinton, published in 1936.

In the several years following this wind study project, Stout carried out research in instrument and control-device design problems, and in 1943 accepted the responsibility for teaching and research in electrical instrumentation.

During the period 1930-36 Attwood and Dow employed the then newly devised Du Four type of cold-cathode continuously pumped cathode-ray oscilloscope as a research tool for investigating the properties of alternating-current arcs between metallic electrodes and surge voltage breakdown problems.

Attwood continued research in electric and magnetic field properties, including studies of special magnetic field problems in electric welding production apparatus, but with particular emphasis on electromagnetic wave propagation. During World War II, while on leave of absence, he served as director of the Columbia University division of the War Research Wave Propagation Group and contributed much to the military program. After the war he pursued this work actively, his outstanding contribution being the compilation and editing of the three-volume summary report of the committee's work. The growth and development of the graduate student research program in electrical engineering have been largely the result of Professor Attwood's inspiration and guidance in technical, policy, and personal matters.

Between 1924 and 1932 Moore conducted a successful study of quantitative graphical methods of determining the flux and equipotential maps for two-dimensional electrostatic, magnetic, and elastic stress fields, and laminar fluid flow fields in irregular geometries not easily amenable to mathematical study. Between 1947 and 1952 he invented and developed a fluid flow mapping technique which permits completely quantitative studies of irregular fields present in a great variety of engineering problems. Between 1924 and 1940 Moore pioneered various methods in the study of heat transfer as applied to electrical apparatus and developed experimental methods for solving such problems, particularly in relation to arbitrarily complex time transients in heat flow problems.

Departmental research in photometry, illumination, and the laws of natural lighting was directed by Higbie from 1910 until his death in 1947. He was assisted in this work by several graduate students, particularly Wilfred Alexander Bychinsky ('30e [E.E.], Ph.D. '33) and

John Melvin Lyon ('33e [E.E.], Ph.D. '36), whose theses grew out of the illumination problem. Higbie's most notable contributions to the knowledge of lighting occurred between 1924 and 1941. Before 1924 window areas in buildings were determined by rule of thumb. Higbie, in various papers published in the Illuminating Engineering Society Transactions, put the design of natural lighting of interiors on a scientific basis. Theoretical formulae for use in window design were developed and confirmed in models and in finished buildings of complicated fenestration. Single and multistoried buildings, monitor and saw-toothed roof structures, schools, and offices were all treated in these studies. Related research in the same field was done by H. S. Bull in the 1930's. Little more was accomplished during World War II and until 1951, when Bull completed an investigation dealing with the control and redirection of daylight in schoolrooms by means of various types of louvre systems. This was studied on a scaled model by using an artificial sun and sky. Hedrich also contributed to this program an analysis of the illumination patterns from fluorescent luminaires.

From 1927 to 1945 Holland directed an extensive series of doctoral thesis projects in the field of communication and related electronic applications. During World War II he worked with the Department of Physics and the National Defense Research Committee on uses of infrared radiation, particularly on studies of infrared radar. In 1945 Division 16 reports from this research included: "Development of an Infrared Glider Position Indicator" by G. A. Van Lear, Jr., and L. N. Holland, "A Photocell Test Set" by W. L. Hole and L. N. Holland, and "An Infrared Range and Direction Apparatus for Diffusely Reflecting Targets" by W. L. Hole, W. W. McCormick, and L. N. Holland. In 1950 under the sponsorship of the Office of Naval Research, R. K. Brown undertook an investigation of causes of variations in the

velocity of propagation of sound in sea water.

Dow engaged in research on the use of electron tubes in the manufacturing industries, including studies of the firing time of ignition tubes (with Walter H. Powers ['34e [E.E.], M.S.E. '34]), analysis of space charge control mechanisms in vacuum tubes, and studies of the recovery time of grid control in thyratrons (with Harry A. Romanowitz [Cincinnati '24e [E.E.], Ph.D. Michigan '48]). Dow also initiated an investigation, sponsored by the Fisher Body Division of the General Motors Corporation, of high frequency power for welding sheet metal. This work, carried out under his direction by a team of research engineers and graduate students, resulted in a number of patents.

From 1943 to 1945, while on leave at the Radio Research Laboratory at Harvard University, Dow worked on the development of radar countermeasure transmitters, particularly on microwave frequency electron tubes and equipment and new vacuum tubes a thousand times more powerful than their prewar predecessors. After returning to Ann Arbor, he initiated several major government-sponsored group research programs with the assistance of Gunnar Hok. The earliest of these programs was concerned with the instrumentation of high-altitude rockets for investigation of properties of the upper atmosphere. This undertaking, with Nelson Warner Spencer ('41e [E.E.]) as project engineer, resulted in the development of a successful method of measuring air temperatures to an altitude of about fifty miles, and in the demonstration of a new and potentially valuable means of direct measurement of properties of the E layer of the ionosphere.

Dow also played an important part in the organization of the Willow

Run Research Center, which resulted in substantial benefits to the research and instructional programs of the department. The Center's extensive electronic computer activity was an invaluable starting point for the development of electronic computer research. A powerful microwave radar unit was installed in the engineering laboratories, and a staff of experts able to give consultation and lecture courses in the rapidly expanding fields of electronics, such as microwaves, information theory, and semiconductor electronics, was maintained.

The apportionment of the basic research work at Willow Run to the campus research program resulted in the establishment of a gaseous conduction laboratory which has continued to make valuable research contributions to other problems. The work in this conduction laboratory, under the direction of Harold C. Early (Michigan State '39, M.S. Michigan '41) resulted in experimentation with high-power-level gaseous discharges at microwave frequencies, studies of the production of violent winds at low pressures by ionic forces in gas discharges, the uses of spark discharges in printing, recording, and information storage processes, the behavior of arcs at low pressures in strong magnetic fields, and developments in the use of microwave-frequency breakdown for instrumentation purposes.

Probably the postwar project of greatest direct value to the department was that sponsored in 1946 by the Army Signal Corps to study various aspects of the behavior of microwave magnetron oscillators. This project resulted in the establishment of well-equipped microwave measurement and electron tube laboratories. The contributions resulting from work done on various kinds of electron tubes included theses by Leonhard Wilford Holmboe (Illinois Institute of Technology '41e [E.E.], Ph.D. Michigan '50),

Robert William Olthuis (M.E. Stevens Institute of Technology '44, Ph.D. Michigan '51), George Raymond Brewer (Kentucky '43e [E.E.], Ph.D. Michigan '52), Jules Sid Needle ('43e [E.E.], Ph.D. '52), and Homer William Welch (DePauw '42, Ph.D. Michigan '52).

In 1951 under the direction of Dow with H. W. Welch as project engineer, the Electronic Defense Group was established in the departmental laboratories for the study of various classified military electronic problems. This group represents the equivalent, as to technical staff, of about fifteen to twenty full-time research workers, investigating electronic circuitry at various frequencies extending into the microwave range, radio-wave propagation, electron tube principles, semiconductor electronics, and the use of ferrites as circuit elements. This program has been organized in such a way as to employ the special talents of members of the faculty. Thus, the teaching and research staff have access to the latest developments in electronics and will be able to make immediate instructional and research use of them when military security permits.

Important contributions to this program have been made by Dow, Attwood, Holland, Hok, Macnee, Cline, Scott, Needle, and Rogers of the teaching staff, and Welch, J. R. Black, Orr, and Boyd of the research staff. Many of the resources of the electrical engineering laboratories are of great value in this work, particularly the analog computer facilities, the electron tube laboratory, and the microwave instrumentation laboratory.

The first significant research by the department in electronic computation was begun in 1946 by Kazda. Later, work was carried out on gaseous conduction and semiconductor electronics by Early and Lyman Walton Orr (Toronto '43, Ph.D. Michigan '49). In 1949 the

University began the construction of a flexible analog computer unit patterned after the designs employed at the Willow Run Research Center. This unit, completed in 1952, has been used extensively by Macnee in solving important Electronic Defense Group problems.

Gomberg has carried out research on the use of high-frequency power in powder metallurgy, on new methods of electromechanical energy transfer, linear motor systems, a series generator shunt motor oscillator, and on electrically generated heat transients to determine suitability for metal continuity testing. In nuclear engineering he has worked on the development of a high resolution radiation detecting layer (autoradiography) and of a radiation microscope for direct location of radioactive centers in solid state structures, under support by the Atomic Energy Commission, and on application of new methods of autoradiography to metallurgy. With the Medical School's Department of Radiology he has studied thyroid disorders by means of radioiodine. He has also worked on the mechanism of radiation damage and the development of a new X-ray spectrometer. In the Phoenix Project the construction of a mass spectrometer has been designed for stable isotope studies.

Dynamoelectrical machinery. — The history of electrical machinery at the University of Michigan began in 1874 with the purchase of the first machine, a self-excited alternating-current generator, built by W. Ladd, of London. The machine, which was ordered by Albert Prescott, Professor of Organic and Applied Chemistry and Pharmacy, was intended for work in connection with electricity and magnetism, but for some reason it could not be made to generate and so was never used.

At this time Professor George P. Williams was lecturing on general

physical theory and analytical mechanics. An article in *The Chronicle* of October 31, 1874, deplored the lack of aid to Williams' physics laboratory while the Department of Chemistry was "abundantly supplied." The writer stated: "Money has been lavished on rare, costly, and, in some cases, frail machines, such, for example, as the 'Ladd's Machine,' which cannot be coaxed into a display..." This "frail machine" weighed over half a ton. Rehabilitated and operated in the 1930's, it is now the oldest machine in the museum of the Electrical Engineering Department.

In 1875 John W. Langley joined the faculty, and under his leadership the study of electrical machinery gained headway. The second oldest machine in the historical collection is the Langley generator, built in 1876. This generator was successful, and a factory was established in Ann Arbor to manufacture machines of slightly modified design.

The Physics Laboratory was established by a state legislative appropriation in 1887, and, when completed, became the headquarters for work in electrical machinery. The first instruction in dynamoelectric machinery was offered in 1888-89, a three-hour course with laboratory. Under Carhart's guidance, several successful alternators, transformers, and motors were built by students doing advanced work.

In 1905, a year after Cooley became Dean of the College, the Electrical Engineering Laboratory was set up in the basement of the West Engineering Building. Nine rooms with a total floor area of approximately 5,000 square feet were used for dynamo laboratories, telephone and telegraph, photometry, calibration, and research.

The work in machinery entered a comparatively modern phase of

development coincident with the removal of the Dynamo Electric Laboratory to the north wing in 1910. About 7,000 square feet were provided in the basement, where it was possible to lay out a flexible and convenient system of mounting machines for test and for making connections to the proper power supply.

Instruction in direct-current and alternating-current machinery has always been supplemented by various courses offered in design. An early course listed was Design of Electric Machinery and Appliances. Another, entitled Advanced Alternating-Current Machinery, was offered first for two hours of credit and later for three. Such courses developed until in 1951 a four-hour required course was given in field mapping and heat transfer, and optional courses were offered in induction motor design and in direct-current and synchronous machine design.

Motor control and servomechanisms. — It early became apparent to the staff of the Electrical Engineering Department that instruction in the control of electric motors would be an important addition to the curriculum. In 1915 Professor Lovell organized a course dealing with the magnetic control of motors, which by 1952 included magnetic and electronic closed-loop control. Numerous examples of magnetic and electronic motor control are studied in the machinery laboratories of the department.

The first course in servomechanisms was organized by Gault in 1944 as part of the University's armed services program. In this course the fundamental theory of closed-loop systems was presented to trainees, and in a co-ordinated laboratory period simple closed-loop systems were analyzed. With the termination of the war the theoretical content of the course was expanded, and it was offered at the

graduate level. As control system complexity increased, it became apparent that additional instruction in servomechanisms was necessary. Since 1950 this added work, in which the multiple loop and nonlinear systems as well as component designs are considered, has been offered by Kazda. A recent addition to the Servomechanisms Laboratory has been an analog computer, one of the functions of which is to simulate closed-loop systems.

In 1949 a course entitled Motor Control and Electronics was organized to present basic electronic and motor theory to mechanical engineering students.

Lighting. — Instruction in lighting and in measurement of light (photometry) was included as a requirement in the first electrical engineering curriculum in 1889. Patterson, who was appointed Instructor in Electrical Engineering in that year, first developed the work in lighting. As early as 1894 he translated and used as his textbook the *Treatise on Industrial Photometry with Special Application to Electric Lighting*, which Professor A. Palaz had published in Paris only two years before. This book was devoted entirely to light production, measurement, and control and distribution, in contrast to Crocker's *Electric Lighting*, which was largely used in other colleges and was concerned particularly with the generation and distribution of electric power for lighting.

In 1913 Higbie took charge of the work in lighting. The original required course in lighting had been expanded by 1920 to two hours. Graduate instruction in interior illumination was first offered in 1924. In 1929 another graduate course, *Natural Lighting of Buildings*, was the outgrowth of Higbie's extended research on daylighting of interiors.

Design.-Activity in the field of electrical machine design at the University of Michigan began in 1876, with the construction of Professor Langley's generator for arc lighting. Formal courses in design, however, were not introduced until much later. The first course restricted to design was Design of Electrical Machinery and Appliances, given in the Department of Physics by Carhart in the second semester of 1894-95. This course was transferred in 1896 to the Department of Electrical Engineering.

Bailey was in charge of the work from 1906 to 1922, and the design courses developed greatly under his guidance, benefiting from his technical knowledge, practical experience, and analytical skill. He introduced an elective course dealing with the design of induction motors, a field in which he attained prominence and in which he published extensively.

Moore took charge of the Design of of Electrical Machinery and Appliances course in 1922 and made numerous changes in the content, partly in response to the increasing emphasis on fundamentals in engineering education. He soon introduced work in graphical field mapping and added instruction in heat transfer. In connection with this work Moore invented and patented the hydrocal, a hydrodynamic computing machine for solving difficult heat transients. When he brought out his Fundamentals of Electrical Design in 1927, the design course was given the same name.

Through his publications and the men he has trained, Moore is recognized as an authority on field mapping. His fluid mappers are an outgrowth of his long-time interest in mapping fields. In a fluid mapper, streamline fluid flow made visible and occurring between a

slab of dental stone and a piece of plate glass is made to simulate an electrostatic, a magnetic, or other analogous field. The flow pattern can lead to the solution of the field problem. Since 1948 Moore has developed fluid mappers so that they can be simply and cheaply made up.

Power plant courses. — The field of power generation and distribution is one of the oldest in the department. A four-hour course, Distribution of Electricity and Photometry of Electric Lamps, was offered by the Department of Physics in 1889-90. In 1896-97 a three-hour course with the same title was taught in the Engineering Department by Patterson. In the following year the distribution work was given separately as a two-hour course under the title Distribution of Electricity. Two new courses, Electric Generating Stations, taught by Ernst Steck for one hour of credit, and a two-hour course, Electric Railways, given by Patterson, made their appearance in 1904-5. In 1906 Bailey took over the lectures in the power group.

Lovell, assigned to teach power courses in 1913, increased the instruction available by introducing Design of Electrical Power Plants and Transmission Systems in 1913, and in 1915 Rates and Cost Analysis and Industrial Electrical Engineering, all two-hour courses.

In 1916-17 Parker, then head of the Electrical Engineering Department, took over supervision of the power courses, and in 1919 an advanced course, Transmission, was introduced, and the two basic courses, Distribution of Electricity and Electric Generating Stations, were combined and offered as Power Plants, Transmission, and Distribution.

In 1922 Lovell was given charge of the power group. His

development of this work is illustrated by his text *Generating Stations*, first published in 1930 and subsequently revised. Melville B. Stout introduced the course *Electrical Rectification* in 1929 and *Circuit Analysis by Symmetrical Components* in 1934.

When Lovell became Assistant Dean of the College some of his courses were taught by other members of the department, but on his appointment as acting head in 1944 and as chairman of the department in 1945, he again supervised the instruction in this field.

In 1946, to allow students studying electronics communication additional time for course work, *Economic Applications in Electrical Engineering* was introduced to replace the required course, *Power Plants and Distribution Systems*. *Power System Stability* was introduced in 1951 by John J. Carey, who had assisted Lovell in the power field since 1946. J. G. Tarboux has had extensive teaching experience in power and machinery and has published several standard texts on these topics.

Electronics. — In the early 1920's electronics first gained recognition as an important branch of engineering. The College of Engineering of the University of Michigan was one of the first engineering schools in the United States to include instruction in electronics as a major item in its curriculum. At that time the term generally implied attention to the physical functioning mechanisms of electronic devices and apparatus such as vacuum tubes and mercury-arc rectifiers. The first course properly called electronics was *Thermionic Vacuum Tubes in Engineering*, introduced in 1929 by Holland, who was also in charge of courses in communication engineering.

Plans for extension of this type of electronics instruction were made

early in 1929 by a committee consisting of Attwood, Holland, and Dow. The plans led to the introduction by Dow of Fundamentals of Engineering Electronics which was offered as an elective but in 1931 was renamed Electronics and Vacuum Tubes and added to the list of courses required for graduation in electrical engineering. This course represented a major step in that it introduced in the junior year on an analytical level, as a required part of the electrical engineering curriculum, the noncircuit study of the internal function of electron devices as contrasted with the almost exclusive emphasis on electron tube circuitry prevalent in undergraduate instruction elsewhere. This step was made possible by the presence of courses already in the curriculum which emphasized noncircuit electrical engineering, particularly Principles of Electricity and Magnetism, introduced by Fairman and Attwood in the middle 1920's. Emphasis on the physical electronic aspects of electron devices has been maintained; it has contributed substantially to the establishment in the electronics field of the strong position which the department now holds.

Courses on the graduate level dealing with the internal behavior of electron devices were introduced in 1936. These included Theory of High Vacuum Electronic Devices and Gaseous Conducting Electronic Apparatus, both given by Dow. Microwave Electron Tubes was given by Dow and Needle, and Electron Beam Tubes by Dow in 1946. Hok offered Semiconductor Electron Devices in 1952. These courses represent an important step in the transfer to the engineering arts of subject matter heretofore largely dealt with in physics curriculums.

The word "electronics" has come to have an all-inclusive meaning, referring generally to systems and equipments employing electron devices as major elements in their functioning. Correspondingly, instruction dealing with the applications of electronics in industry

has been introduced in electrical engineering.

Courses dealing with or related to industrial applications of electronics have been Motor Control and Electronics, an undergraduate course for students in other engineering departments, taught by Gomberg in 1947; Industrial Electronics, which attempts to maintain an up-to-date introduction to new electronic arts, offered by Dow in 1939 for seniors; Photoelectric Cells, an undergraduate course dealing with characteristics and uses of photosensitive electron devices, given by Bull in 1930; and Servomechanisms, a graduate-level course, incorporating both the electronic and electric machinery aspects of the subject, was taught by Gault and Kazda in 1945. A course called Seminar in Electronic Computer Technology was offered by N. R. Scott, J. DeTurk, and L. E. Kolderup, of the Willow Run Research Center of the Engineering Research Institute in 1952. The planning and organization of this course represent a valuable correlation between university research and teaching activities, for the major instructional load is carried by experts in charge of analog and digital computer developments in the University's research program in electronic computer techniques. Nuclear Engineering Measurement and Instrumentation, introduced by Gomberg in 1952, represents the contribution of the department to the development within the College of training in nuclear engineering.

The use of electronic devices and apparatus has spread into almost all areas of electrical engineering work, so that it is now difficult to define the boundaries of electronics. The study of electronics, as well as the study of electric circuitry, electromagnetic field theory, instrumentation, and electric machinery is becoming important to all electrical engineers. This has been recognized by the inclusion of electronic measuring and control techniques in machinery and power

laboratories in addition to the communications and electronics laboratories.

In 1946, with the Aeronautical Engineering Department, the department undertook a program of instruction in guided missile technology for Air Force officers. The electronics aspect of this program is a series of courses extending through four years.

During the summer sessions of 1937 and 1950 the department offered eight-week Electronics Symposium programs in which visiting lecturers were presented. In 1937 these lectures dealt with high vacuum electron tubes and gaseous conduction principles. In 1950 the subjects were microwave electron tubes and semiconductor electronics. These well-attended programs, by attracting teachers from many states, enabled the large electrical corporations to help strengthen instruction in electronics. Since 1938 two extension courses in electronics have been offered in Detroit.

Communications. — Although telegraphy was the first practical application of electrical engineering, it was not until 1900-1901, eleven years after departmental instruction had been established, that the first work in electrical communications was offered. In the second semester of that year, Patterson taught a course entitled Telephone and Telegraph. By 1913 fourteen credit hours were devoted to work in communications. In 1912-13 instruction in radio, wireless telegraphy and telephony, was introduced.

Morehouse taught in this field until 1910, when he joined the staff of the American Telephone and Telegraph Company. From 1907 to 1920 courses were given by Parker, Sheppard, and Evans. A milestone in the development of this program was reached in 1922 with a course

in the advanced study of electrical circuits, primarily in telephone communication. Together with a course in radio, this constituted the backbone of the communications program until 1940. The electrical circuits course, taught for two years by E. E. Dreese, was taken over in 1924 by Cannon, who gave it for twenty-five years. Recently it has been taught by Holland and Cline. From 1926 to 1940 instruction in radio was given almost entirely by Holland. Hellwarth, who was a member of the communications staff from 1927 to 1931, taught specialized courses in telephone and telegraph.

As a result of World War II, a course in microwave engineering and one in radio communication were added to the curriculum. Another important addition, a course in radiation and propagation, has been given by Attwood since its introduction in 1946. Of prime importance in communications is the development that has taken place during the past ten to fifteen years in network synthesis. Two courses in this field have been offered by Macnee. Instruction in television has been given since 1939.

A history of the communications program would not be complete without some reference to the radio stations which have been built and operated by the department. In the engineering Announcement for 1912-13, under the description of electrical engineering laboratories, a five-kilowatt transmitting set with antennae 150 feet high and capable of sending 500 miles was described. This, the University's first powerful radio station, 8XA, was well known during the years 1913 to 1917.

In 1923-24 students of the department, under the direction of Dreese, constructed a 200-watt broadcasting station, with the call letters WCBC. The first regular radio program, a broadcast of the Michigan-

Purdue basketball game, was sent out on February 16, 1924. After a year of successful operation the station was discontinued owing to lack of funds.

The famous spark transmitter, 8XA, was closed during World War I and not reopened. In 1926, however, the Electrical Engineering Department and the Signal Corps Unit of the R.O.T.C. built a short-wave radio station which operated in the 40-meter amateur band under the call letters W8AXZ. This station was rebuilt in 1927 and again in 1936. In 1930 a fifty-watt twenty-meter telephone transmitter was added to the station complement. W8AXZ became as well known as its predecessor, 8XA, largely because of its work with University of Michigan expeditions in South Africa and in Greenland and with Admiral Byrd's first expedition to the Antarctic. This station for many years also maintained contact with the University Surveying Camp in Wyoming during the summer months. It has operated only intermittently since World War II.

Electrical measurements. — A required course in electrical measurements was given in the department as early as 1895. It covered topics more advanced than those treated in the required undergraduate measurements course, then offered in the Physics Department.

Undergraduate instruction was taken over by the department in the fall of 1945 in a new course, which was placed later in the curriculum than the previous study of measurements in order to permit increased prerequisites in electrical circuits. The development of the laboratory began when the department was moved to the new quarters in the East Engineering Building. Laboratory facilities were greatly increased in order to handle large postwar enrollments. In

addition to the regular instructional material, the departmental calibration equipment was mounted for permanent and convenient use. An elective course which deals with electrical methods of measuring physical quantities, such as strain, torque, speed, and acceleration, was introduced in 1947.

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Alfred H. Lovell

SELECTED BIBLIOGRAPHY

Announcement, College of Engineering (title varies), Univ. Mich., 1906-52.

Calendar, Univ. Mich., 1880-1914.

Catalogue ..., Univ. Mich., 1914-23.

Catalogue and Register, Univ. Mich., 1923-27.

The Chronicle, October 13, 1874.

General Register, Univ. Mich., 1927-52.

President's Report, Univ. Mich., 1920-52.

Proceedings of the Board of Regents ..., 1886-1952.

Special Announcement, College of Engineering. Univ. Mich., 1914-52.

The University of Michigan, an encyclopedic survey ... Wilfred B. Shaw, editor, Volume III, Part VII, pp. 1219-1233.