THE DEPARTMENT OF ELECTRICAL ENGINEERING

A 75-YEAR HISTORY (1895-1970)

College of Engineering

The University of Michigan

FOREWORD

Seventy-five years ago at The University of Michigan, Electrical Engineering split off from the Department of Physics to become a separate department. I have collected here a few bits of history and a few informal anecdotes to help commemorate this important event.

The Department's history was first compiled by the EE staff back in 1953–54 for the Centennial of the College of Engineering. That history, of which I have made liberal use, was published in THE UNIVERSITY OF MICHIGAN—A CENTURY OF ENGINEERING (U of M Press, 1954). This is a good time to bring the history up to date because so much water has passed over the dam since it was written. We are fortunate today that six emeritus professors are still alive: H. S. Bull, W. G. Dow, L. N. Holland, E. R. Martin, A. D. Moore, and M. B. Stout. Their work and experiences at Michigan extending back more than 50 years are an important part of the Department's history. I wish to express thanks for their help and guidance in writing this 75-year history.

One of the best sources of information on the early days of Electrical Engineering at Michigan is a long, unpublished document written by Benjamin F. Bailey in 1944 when he retired as Department Chairman. A student when the Department was first formed, Bailey remained for a lifetime of distinguished service, and became one of Michigan's grand old men. He was not at all hesitant in describing quirks of his teachers and rough spots in the curriculum, and I have made use of his document to add spice and interest.

The ANNOUNCEMENT OF THE COLLEGE OF ENGINEERING, a yearly publication, contains brief course descriptions and is an excellent record of curricular changes. The Department's Research Laboratories have generously supplied information on their history and current activities. I wish to express my thanks to T. W. Butler, G. R. Carignan, J. L. Cochran, W. G. Dow, R. E. Hiatt, J. E. Rowe, E. D. Sybesma, and W. J. Williams for this material. The U–M Information Services and the Michigan Historical Collections have supplied some of the photographs used in Section IV.

Richard K. Brown

Ann Arbor, Michigan
June 1970

THE DEPARTMENT OF ELECTRICAL ENGINEERING

A 75-YEAR HISTORY

I

THE EE DEPARTMENT

The academic year 1895–96 marked the beginning of the Department of Electrical Engineering at The University of Michigan. As early as 1888–89 a course in dynamo-electric machinery had been given at the University, but it was offered through the Department of Physics.

The man who taught this pioneering course was Professor Henry Smith Carhart. The laboratory equipment that he had to work with, installed in the east basement room of the Physics Laboratory, was meager indeed. It consisted of a 25-horsepower high-speed steam engine driving a line shaft, an Edison dynamo with arc lamps, a 5-horsepower constant potential motor, and a Brackett cradle dynamometer. Adjacent to the Laboratory were a small photometric room and a battery room containing a 31-cell storage battery.

Carhart's machinery course was soon followed by courses in electric distribution, photometry, transformers, and the design of electric machinery—all offered through the Physics Department. George Washington Patterson was appointed an Instructor in Electrical Engineering in 1889, and the next year the first three degrees in this specialization were granted. Five years later, in 1895, there were enough courses and staff members to warrant an important change. The University's offerings in Electrical Engineering were separated from its offerings in Physics, and the Department of Electrical Engineering came into being. Patterson was its first chairman, serving until 1915.

Benjamin Franklin Bailey was a student under Carhart in those early days, and later served as Chairman of the EE Department for 22 years. Writing in 1944 shortly after his retirement, Ben Bailey has left us some lively recollections. Those regarding Carhart are among the liveliest:

> The founder of the Electrical Engineering Department was Professor H. S. Carhart. He never held the title of Head or Chairman of the department but remained Professor of Physics as long as he was here. I remember that he once told me that no one was ever authorized to start such a department, but like Topsy, it "just grew." I think it is safe to say that no one who studied under Carhart will ever forget him. He was a small, nervous man, full of energy and "pep." He was a good lecturer, but not very profound. It was rumored among the students that he had stomach trouble and that this was why he was so sour. His pet aversion was blown fuses and each case called for a thorough investigation. The poor culprit did not hear the last of it for many a long day. In his

laboratory classes, we lined up outside the door. Promptly at one o'clock the doors opened and we filed in. Everything was "hooked up" and we were each assigned to read an instrument. When we were "all set," "hydrogen sulfide" as he was called (for obvious reasons), started the motor and the experiment proceeded. It is a fact that I was the only student in my class who ever even started a motor and that was because I sneaked in at night to see if I could do it.

Most of us are prone to look back with nostalgia to the "good old days." By comparison with modern standards, however, this description of early electrical engineering could hardly be called good. Back in 1885, equipment replacement in the student laboratories must have been a sore point! Students have not changed very much, and today it is not unusual for them to burn out an occasional meter. The difference is that teachers today have come to accept this as part of the process of learning. It is significant that Bailey, "the only student in his class to ever start a motor," invented the capacitor motor in the middle 1920s. This invention, one of the major advances in single-phase motor development, proved to be a milestone in electrical engineering progress.

From its beginning, the EE Department continued to grow steadily. By 1904, as soon as half of the present West Engineering Building was completed, the Department moved out of the Physics Laboratory and into the south end of the new building's basement. To us, "new" sounds inappropriate for "West Engin," but both new and modern it must have been back in 1904. The next year Patterson was appointed the first Professor of Electrical Engineering—and is thus the only man in history to have been made Chairman first and Professor second. Patterson's Christian name, "George Washington," sounds peculiarly appropriate for the Department's first Chairman. Bailey's comments on Patterson are interesting:

He was undoubtedly the best loved of our teachers and is still thought of by his old students as "Pat." He was by no means a "practical" engineer but he was a thorough mathematician and had a wide grasp of electrical theory. As a teacher he was very poor except for the better students as he never could realize that students were not as brilliant as he was. If he ever "flunked" any one I never heard of it. He never wrote or carried on much research but was nevertheless one of the strong men of the faculty. For those who could "take it," he was a real inspiration.

The number of courses offered during the decade 1905–15 increased from 16 to 32 and the staff grew from four to eight members, with two assistants. Part of this growth came from the introduction of required courses in electric communication work, which was at first under the direction of Lyman Foote Morehouse. Morehouse's success in this field led to his resignation in 1910 to join the American Telephone and Telegraph Company.

Others who joined the EE Department at an early date are Henry Harold Higbie (1905) and Alfred Henry Lovell (1910). Higbie transferred from Mechanical to Electrical Engineering, and is remembered for his work in illumination. Thanks largely to his efforts, Michigan became one of the leading US universities for study in illumination. Lovell had interests and experience in power-plant work, and was responsible for a group of courses relating to power-plant design and transmission (with special emphasis upon economic aspects of power generation and utilization). In 1930 Lovell became Assistant Dean of the Engineering College, and in 1945 became Chairman of the EE Department.

When the north end of the West Engineering Building was completed in 1909, the Department's dynamo laboratories were moved into it. The communications laboratories were left in the south end, and a little later the illumination laboratories were moved to the attic. Thus the Department, like ancient Gaul, was divided into three parts. Geographical division has characterized the Department to this day; its research and instructional facilities are now located in many widely separated places.

In 1915, Professor Patterson left the EE Department to become Chairman of the Department of Engineering Mechanics. John Castlereagh Parker took his place as EE Chairman. Parker had a background of extensive power system experience and a decided inclination toward scholarly pursuits. He remained with the University until 1922, during a period of rapid expansion; and under his chairmanship, radical changes took place in the Department's curriculum and general philosophy. To the staff, it was quite evident that electrical engineering was "growing up."

In the early days, it had been possible within four years to give the student a fairly comprehensive picture of the entire field of electrical engineering, including details of practice. As the theory of electrical engineering advanced, however, books and articles in the field became more numerous and increasingly mathematical in character. At the same time that the engineer was expected to know more theory, the applications of electricity were being widened in scope.

Radio became important, and the science of electronics developed. Obviously it was no longer possible for students to cover the entire field as they had previously. One possible solution was to specialize. Through specialization a student might graduate with detailed knowledge of telephone practice, for instance, but with little or no knowledge of dynamos or motors. Yet this solution was not adopted by the Department; its faculty felt that specialization should come after graduation, not before.

In deciding against specialization, the Department was supported by the large electrical companies, which offered the graduate an opportunity to discover his special interests and to learn the practical applications of electricity under the best possible conditions. Accordingly, the Department discontinued its practical and more or less descriptive courses, thereby reducing the 32 courses given in 1915 to 23 given in 1919. Concurrently, new work of a theoretical nature was introduced and course offerings were gradually increased. Throughout this period there was a general stiffening of requirements.

In this brief history, it is not possible to mention everyone who has served on the staff of the EE Department. Many who served with distinction must be omitted—especially those who stayed at Michigan only a short time before leaving to acquire fame and prestige elsewhere. Still, in looking back one is impressed with the stability of the Department's staff during these middle years.

Arthur Dearth Moore was appointed instructor in 1916. Advancing rapidly through the various grades, he arrived at that of professor in 1931. "A.D." (as he is fondly called by his associates) pioneered in bringing heat transfer into the electrical engineering curriculum, and made outstanding contributions to the teaching of electrical design. It has been said that many students did not appreciate A.D.'s difficult course until about ten years after graduation; then they began seeking his advice and counsel. His enormous correspondence with alumni and friends illustrates the point. In retirement, A.D. refuses to take it easy. He continues to write (recently having published two books) and to give his lecture-demonstrations across the country. When in Ann Arbor, he still bicycles to his laboratory-office in East Engin to keep regular hours. As toastmaster, model builder, engineering crusader, A.D. has no peer.

Joseph Henderson Cannon joined the staff as an associate professor in 1917, and advanced to professor in 1920. For many years he had an important role in the direction of department policy, and greatly strengthened the teaching of circuit theory by adding such theoretical courses as "Electromechanics" and "Heaviside Operators." In "Uncle Joe's" class, many a student learned the hard way that DC does not pass through a capacitor—at least in theory. At one historic student-faculty banquet, Cannon was given a short-circuited capacitor as proof that theory and practice don't always meet!

Having joined the EE Department staff in 1920, Stephen Stanley Attwood rose to become first Department Chairman and then Dean of the Engineering College. Many of us recall Steve as a soft-spoken, steady individual, who demonstrated his outstanding administrative ability at an early age. In Departmental meetings it was not unusual for him to sit patiently silent while others were debating some question in detail. When it became apparent that the question was hopelessly deadlocked, Steve would speak briefly, indicating the perfect solution that no one else had been able to see. In one instance, the topic under consideration was a particular course of instruction. The man who taught this course was not present at the meeting, and in his absence, everyone agreed that the subject material was important enough to carry three hours credit rather than two. Yet it was reported that he did not have enough time that semester to work up a lot of new material. Steve's solution was classically simple: "Have him talk slower." Steve's teaching was in the area of electric and magnetic fields, a subject that became very important at Michigan largely because of him. His book ELECTRIC AND MAGNETIC FIELDS has become a classic.

Others who joined the staff during this era are Melville B. Stout, Hempstead S. Bull, and James D. Gault (all in 1922), Lewis N. Holland (1924), and William G. Dow (1926). Bill Stout developed strong courses in measurement and instrumentation. His measurements laboratory, a model of organization and neatness, was always the first stop on a visitor's tour of the Department. A student once said that the most catastrophic technical misfortune possible for Professor Stout would be to have someone short-circuit one of his standard calls—even momentarily. "Hempy" Bull, patient teacher, good friend, started many a young electrical engineer on his career in the DC circuits and machinery course. Jim Gault was the first to bring servo-mechanisms into the curriculum. Lewis Holland contributed much to graduate and undergraduate work in radio and related phases of the communications field. Advisor to countless students, it was estimated conservatively that when he retired, four faculty members and two committees were required to take over his work load. No greater tribute can be given a man!

The Department's increase in research during the past 25 years can be attributed more to Bill Dow than to any other man. In fact, he might appropriately be called "Mr. Research." Graduating from the University of Minnesota in 1916, he served as an officer in the Army Corps of Engineers during World War I. Dow came to Michigan in 1926, after six years of industrial experience including test engineering for Commonwealth Edison of Chicago and testing and sales for Westinghouse. His pioneering work in vacuum-tube design principles and his authoritative text on the subject soon gave Michigan a prominent place in electronics. Dow moved into this field as a power engineer, not a radio engineer, developing a solid background of competence in *electronic science* long before the term became fashionable. He had to do this on his own, because there were then no teachers and very few reliable books to guide the way. The electrical science option (one of three options in the curriculum recently adopted by the Department) had its real beginning back in 1929, when Dow introduced a single course on physical electronics.

Bill Dow advanced steadily at Michigan, becoming Professor in 1945 and Chairman of the Department in 1958. For 2½ years during World War II he worked on radar countermeasures at Harvard's Radio Research Laboratory. Frederick E. Terman, director of that laboratory, has commented on Bill's activities during those hectic days of war research:

> My real acquaintance with Bill Dow began when he was recruited for the Radio Research Laboratory in early 1943. This was a war laboratory at Harvard University which I had been asked to organize and direct. It was concerned with countermeasures against radar, that is, systems for jamming and confusing enemy radar, and with the development of tunable receivers for searching out and analyzing enemy radar signals.
>
> At the Radio Research Laboratory, Bill found opportunities to his liking and quickly became an important factor in the operation of the laboratory. Although he was more than 20 years senior to the typical 25-year old RRL staff member, Bill responded to the situation in the same way as did the best of our youngsters; he blossomed forth in a way that was most helpful to the war effort, and also most gratifying to me personally. This was very unusual for a man of his age, and came about through a combination of some sterling personal qualities and the fact that the

grinding years of the depression had not broken either his spirit or his intellectual drive. In our project at Harvard, we were desperately short of men over 30 years old. Accordingly, since Bill was 47 we made him a group supervisor, even though he had had precious little administrative experience. His assigned activities were in the then unexplored area of very high continuous wave power at very high frequencies, meaning kilowatts of average power at frequencies running from 500 mc up to 10,000 mc.

Bill rose to this challenge magnificently. He put together a group of men who made steady progress in working out the technical problems that were involved. We found that his judgment was sound, and that he did not let his hopes cause him to ignore the facts of the situation. He quickly became the principal spokesman for the laboratory in dealing with outside groups in the matter of high power tubes.

Bill happily turned out to be an excellent administrator. His group got things done, and did so without generating personnel problems. He also proved to be excellent in coordinating activities, in working with groups both inside and outside the laboratory, and in liason work. He was one of the people in the laboratory that we could trust to take full responsibility for establishing a laboratory viewpoint, and to make policy decisions that would commit the laboratory as a whole. On one occasion we sent him on a mission to England. On another occasion he spent a considerable period in Chicago getting one of our big transmitters through the shops of a manufacturer in a situation where there had been a great deal of stress and strain generated by others. It may or may not surprise you, but with his forthright manner Bill turned out to be exceptionally successful as a mediator in quieting troubled waters. This was in part because Bill was completely above-board, because all parties recognized that he was absolutely honest, and because he always put first priority on getting the job done. When handling temperamental people he invariably displayed tact, consideration, and good humor.

What really endeared Bill to me, however, was the fact that having mastered this knowledge, he could never stop being a teacher. In spite of the pressures of the war—which meant exerting great efforts to get specific things done and done very quickly—Bill just had to share his understanding in depth of these new technologies with the young men around him. He couldn't stand for just telling them what to do—he also had to teach them the *why* of what they were doing, and to give them the broad perspective involved.

The result of this was that in the basement floor of the RRL building where Bill's group was installed, an almost continuous seminar went on in Bill's office, hour after hour, day after day, week after week, month after month. Sometimes the participant would be a group from Bill's staff; sometimes a single individual. Often they would be visitors from Washington or England, not infrequently with high military rank. On still other occasions they would be key men from industrial research laboratories located in Schenectady, Pittsburgh, or elsewhere. However, who-ever was the beneficiary of these seminars or lectures, be he a single individual or one of the group, someone very important, or a very young neophyte, Bill always acted his part as though he was lecturing to a large class. His voice would leak out through the woodwork and resound up and down the corridors, and everyone could tell that Bill Dow, the teacher, was hard at work and that all was well.

Bill's interest in the development of the young people around him during the war was matched by their devotion to him. We never had any problems with his boys wanting to transfer out of his group to do something else. Moreover, it is significant that a year or so after the war was over and RRL was no more, a surprising number of these young people who had worked with Bill at Harvard were to be found at Michigan, as graduate students, as research associates, or as staff members. These men with their unique war experience had a choice of many attractive opportunities, but they selected some form of further association with Bill Dow.

At the end of the war, when Bill returned to Michigan, he was 50 years old. This is an age when most research oriented people begin to show signs of slowing down a little. With his war experience, it would have been easy for Bill to have settled comfortably into an educational administrative job, and to have allowed technological obsolescence to set in in a graceful way that would have been hardly noticed, and which no one would have criticized. But this was not for Bill. He kept up a full head of steam that he had generated during the war, and if anything added a little pressure to it.

Everyone who has worked with Bill Dow will recognize the accuracy of Terman's description, given in December 1964 at a seminar on "New Research Frontiers in Physical Electronics." The seminar honored Dow on his retirement from teaching, although "retirement" is not a wholly accurate term. In the sense of continuing to exert influence, Bill will never retire.

At this 75th anniversary of the founding of the EE Department, no one who was teaching in the Department before World War II is still doing so today. For those of us who have long considered ourselves part of the "younger staff," it is a little startling to realize that we are now actually the old guard. Our hair is thinning and turning grey, students seem younger every semester, and many of us tend to vote *against* proposed changes in the curriculum.

However, a Department is different from the individuals within it—at least it ages differently. Under the best circumstances, a Department can grow in size and revitalize itself with new staff and new ideas, remaining young and dynamic as it ages. This seems to be the case with the EE Department in 1970. Just last year, a complete revision of the curriculum was adopted—hardly a sign of comfortable complacency in old age. For one long period of time, however—from 1926 until 1942—the size of the staff remained constant. During those years, with just one exception, the staff consisted of 11 men—Attwood, Bailey, Bull, Cannon, Dow, Gault, Higbie, Holland, Lovell, Moore, and Stout. [For just three years (1930–33) it had a 12th—Arlen R. Hellwarth, who left to join Detroit Edison and returned to the College in 1958 as Assistant Dean.] The unusual stability of the EE staff during these 15 years was due largely to the Great Depression. While the Department grew in prestige and its staff members advanced in both grade and knowledge, its budget remained exceedingly tight.

The 75-year history of the Department has, of course, been profoundly influenced by several wars. During World War II, many of its staff members were called away from Ann Arbor to do research elsewhere; those who remained were asked to work long hours in accelerated programs. Most of the war-time students were members of the armed forces. Arriving in Ann Arbor with great differences in background, they were exposed to a deluge of technical courses and were sometimes unable to cope with them all. The staff deserves great credit for continuing to introduce new courses during those trying times; prominent were the courses in ultra-high frequency techniques and in the propagation of high-frequency waves that helped to satisfy the demands in radar science. Jack Fribley Cline and Henry Jacob Gomberg, added as instructors in 1942, were the first staff additions to be made in 16 years!

After World War II, many veterans took advantage of the G.I. Bill, and enrollments everywhere increased tremendously. The EE Department was no exception. In 1947 it had more than

700 undergraduate students and over 100 graduate students. The returning veterans brought with them a maturity and a dedication to hard work that were both refreshing and contagious. Rarely have so many students been so truly anxious to learn. Classes were crowded, everyone was busy making up for lost time, and not one word of dissent was to be heard. The S.D.S. was 25 years in the future!

During this era, the staff had increased to 28 members: eight professors, three associate professors, one assistant professor, one lecturer, and 15 instructors. Faculty members who came at about this time and have remained are: John Joseph Carey (1946), Louis Frank Kazda (1946), Richard Kemp Brown (1947), Gunnar Hok (1948, retired 1969), William Kerr (1948, now Chairman of the Department of Nuclear Engineering), Alan Breck Macnee (1950), and Norman Ross Scott (1951, now Dean of the U-M Dearborn Center). Edwin Richard Martin was added to the Department staff in 1947 to assist in the course in machine design, and the Department benefited from his excellent teaching until his retirement in 1955. Assistant Professor Walter Alfred Hedrich was appointed in 1947 to help with the work in magnetic fields and illumination. Professor Joseph G. Tarboux, prominent authority of power systems and machinery, joined the staff in 1952. Both Hedrich and Tarboux succumbed to heart attacks in mid-life, and the Department mourned these serious losses.

One important activity that occurs at the beginning of every semester in the EE Department (as in every department of a large university) is the final assignment of teachers to class sections. Often the teaching program must be changed at the last moment to reflect enrollment; then large sections may be split into two, while small classes or laboratories may be cancelled. Teachers are busy people, so the schedule of teaching assignments is always scrutinized very carefully to make sure that the work load has been fairly distributed. One semester Tarboux had been assigned to a morning laboratory in the senior energy conversion course. Since mornings are generally unpopular times for laboratories, only four students had enrolled in this particular section. It was cancelled, and Tarboux was given another, larger section in the afternoon. His instructions were to meet the morning section on its first day and help the four students rearrange their class schedules. When the semester ended, we were greatly surprised to learn that the morning section was still being taught. Why? Because it had proved difficult for the four students to rearrange their class schedules, Tarboux continued to teach the section. He was willing to accept an overload in his own work rather than cause inconvenience to anyone else. Today one of the Department's laboratories is named in his honor —the Joseph G. Tarboux Power Systems Laboratory.

Harry H. Goode, who joined the teaching staff in 1954, was one of the first scientists to fully comprehend the potential capacities and power of computers. He formulated many principles of systems engineering and introduced the course in Large Scale System Design. The Department lost an outstanding scientist and teacher when Goode was killed in an automobile accident in 1960.

In 1947 the new south wing of the East Engineering Building was completed, and the EE Department moved into it. The move was well-timed, as the large enrollment increase could not have been handled in the Department's cramped West Engineering quarters. For example, in 1946 the laboratories for all circuits and machinery courses had been held in a single basement room in West Engineering; and it was not unusual for four laboratories to be running simultaneously in the one room. Along with a much needed increase in classroom and office space, the new building provided the luxury of separate rooms for each laboratory. It also meant that the Department could settle (for a short time, alas) into a single geographical location. The new power and machinery laboratories were located in the basement of the south wing; there were offices and classrooms on the second floor, research and measurement laboratories on the third floor, and electronic laboratories on the fourth floor. With some modification, this pattern survives today. In view of this substantial space increase, it is rather surprising to note for how short a time it satisfied the Department's needs. The tremendous expansion that was about to take place in research soon sent staff members off to Willow Run, North Campus, and to other sites for the space they needed.

During the transitional period 1947-48, some EE classes were held in East Engin and some continued in West Engin. To help the move along, some members of the teaching staff were asked to wire the distribution panel circuits on the top three floors of the south wing and the heavy current switchboards and machinery in the basement. Lovell, then Chairman of the Department and a former Colonel of Engineers in World War I, was instilled with the idea that an officer must lead his men in academic life as well as in the Army. So there he was—a distinguished, white-haired gentleman wearing a black ribbon on his glasses, down in a basement manhole taping electric wires. Under those circumstances, it was hard for the teaching staff to escape doing likewise. Needless to say, there was some grumbling, especially when the wiring went on during weekends and Christmas vacation. But in general the work went well; and fortunately, the short circuits were discovered before the power went on.

One episode during this all-out effort was a Saturday-morning cable-pulling "party" during which heavy wires were pulled from the basement to the fourth floor through conduit. Several professors, associates, and instructors had spent most of the morning on this very strenuous work, and the sweat was flowing freely. Picture a sort of tug-of-war with the heavy cable being unrolled in the basement and the actual pulling taking place on the fourth floor. For most of the morning, several electricians who had been working overtime to finish up the smaller wiring jobs stood watching this faculty activity with amusement and disdain. When the job was almost finished, one of them was overheard to say that he and just one assistant had done a similar conduit job in Detroit. But they had taken the cable to the top floor by elevator and pulled it *down* through the conduit! For some reason, the theoretically minded EE staff had not considered the advantage of using gravity in its favor.

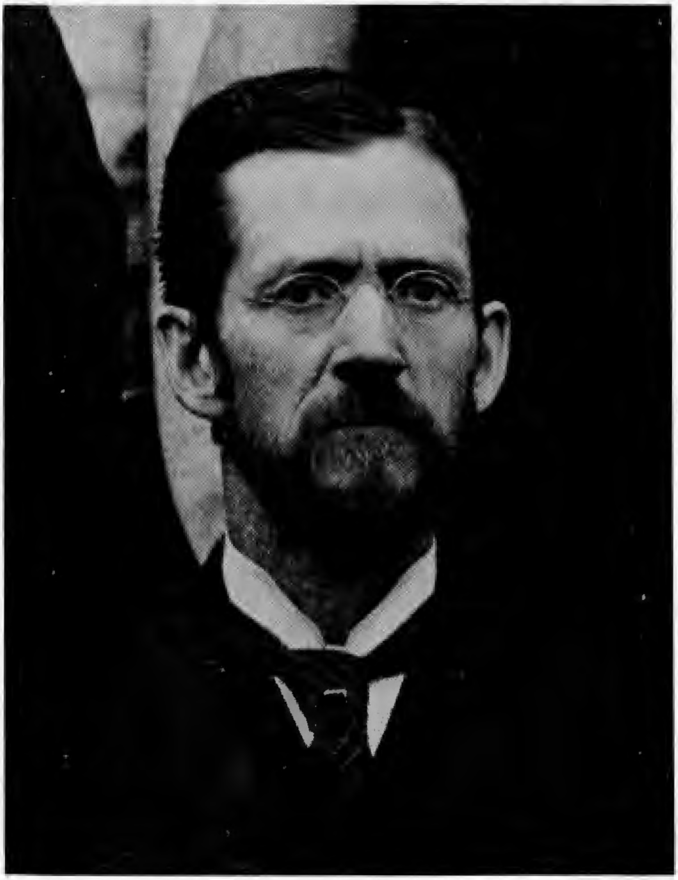
The south wing of the East Engineering Building has served as the home of the Department for the past 23 years. From year to year it has undergone considerable internal change. There has been a notable trend toward smaller room size as partitions are brought in to divide large rooms. Of course there has been a comparable growth in the number of doors. One example of the extensive rearrangement of room space was the creation of a new Integrated Circuits Laboratory in 1969. This laboratory now occupies space on the third floor formerly used for the Measurements and Standards Laboratory, which moved across the hall into a smaller room. Changes like this are simply expressions of the dynamic nature and steady growth of electrical engineering. One sometimes wonders if the entire south wing might not collapse one fine day, as more doors are added and more equipment is squeezed in. But planning is currently underway for new engineering buildings on the North Campus, and the Department has indicated strong interest in moving.

Since Electrical Engineering is itself a "spin-off" from Physics, it is not surprising to find that many subjects once thought to be part of physics are now being taught by the EE Department. Optics is a case in point. EE now offers courses in Modern Optics and Coherent and Non-Coherent Optical Technology; additional optics courses are being added rapidly. Widespread interest has been shown in Michigan as a center for optics research and development. Part of this interest stems from research done at the Willow Run Laboratories, where highly successful results were achieved in the application of optical data-processing to sidelooking radar. There is a close relationship between doppler coherent radar and holography, and the latter is now considered one of the most promising developments in modern science. Emmett N. Leith, a member of the U-M Institute of Science and Technology and a Professor of Electrical Engineering, is generally credited with turning the theory of holography into practical reality. He has received numerous awards for his contributions—among them the Franklin Institute's Ballantine Medal (1969).

In 1965 Hansford W. Farris, former Director of the Cooley Electronics Laboratory, became Chairman of the EE Department. Two years later, when Farris became Associate Dean of the Engineering College, Joseph E. Rowe become the eighth Chairman of the Department. He still holds that position at this writing.

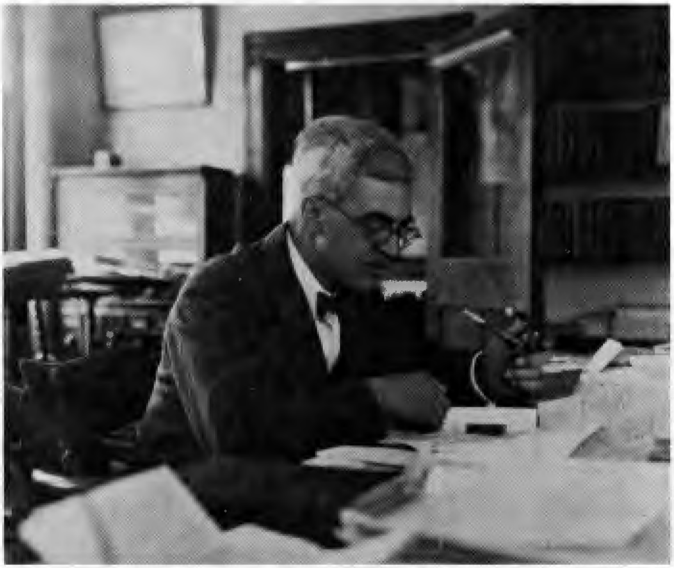
The Department enters its 75th anniversary year with over 100 courses listed in the Engineering College ANNOUNCEMENT, and with a staff of more than 60 members. During the academic year 1968-69, 111 BS degrees were granted in electrical engineering; 74 MS degrees and 26 PhD degrees were granted. This represents about 19% of the total number of degrees granted by the College. An EE graduate at this time can expect to start work with an average salary of more than $800 per month. There is no doubt that the pasture is indeed green on this side of the fence, and that the Department has made remarkable growth and progress during its 75 years of existence. Most of all, the Department is proud that its alumni hold positions of great responsibility all over the world.

THE FOUNDER AND CHAIRMEN OF THE EE DEPARTMENT



HENRY S. CARHART, a professor in the U–M Physics Department, was inadvertently the founder of a new department. His course in Dynamo-electric Machinery began the instruction that soon led to the establishment of a separate EE Department.

GEORGE W. PATTERSON was the first Chairman of the EE Department (1905–1915), and later Chairman of the Department of Engineering Mechanics. This picture was taken in later years, when he served as the College's Assistant Dean.



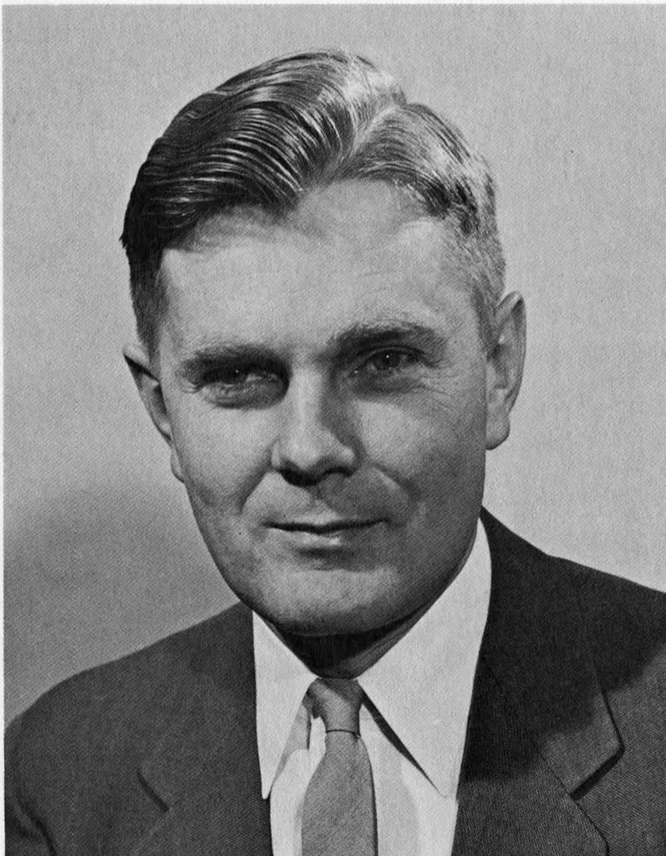
JOHN C. PARKER was Chairman during the critical years from 1915 to 1922. Under his chairmanship, the curriculum was greatly strengthened and the emphasis was shifted from practical to theoretical studies.

BENJAMIN F. BAILEY was Chairman from 1925 until 1944—longer than any other man. This portrait, the only one currently available, was taken long before he became Chairman; for a later photo, see Section IV.

ALFRED H. LOVELL was Chairman from 1945 until 1953—the swelling postwar years, during which the Department moved from West Engine to badly needed quarters across the street.

STEPHEN S. ATTWOOD was Chairman from 1953 until 1958. He left to become Dean of the College, a position he held until his death in 1965.

WILLIAM G. DOW was Chairman from 1958 until his retirement in 1964. More than any other man, he was responsible for building the Department into a large yet flexible research unit.



HANSFORD W. FARRIS was Chairman of the Department from 1965 until 1967, when he became Associate Dean of the College.

JOSEPH E. ROWE is the eighth and current Chairman of the Department.

II

THE EE CURRICULUM

In 1889, the University's requirements for a degree in Electrical Engineering were as follows:

Mathematics		22 hours
French or German		20
English		2
Physics		18
Chemistry		8
Drawing		11
Mechanical Engineering		17
Electrical Engineering		11
Elective		16
Thesis (no Credit)		
	Total	125 hours

Obviously, the tradition of educating a student to be first an engineer and then an electrical engineer was started very early. The number of hours allotted to mathematics has remained about the same, but the large number allotted to foreign language and the small number allotted to English are surprising. [In those days, perhaps students came to the University better prepared in English!]

The 17 hours in Mechanical Engineering included four courses in Shop Work (Pattern Making, Forging, Foundry, and Machine Shop), for a total of 10 hours. Also included was a course in Mechanism (3 hours) and one in Dynamics of Machinery (2 hours), both now given by the Engineering Mechanics Department. The first Electrical Engineering courses were actually listed under Physics; they included Electrical Units and Measurements, Primary and Secondary Batteries, Dynamo Electric Machinery, and Distribution of Electricity and Photometry of Electric Lamps.

The strong emphasis on machinery, distribution, and photometry is clearly apparent. Also apparent is the fact that this 1889 curriculum was much less theoretical than our present program. In fact, some of it was hardly more than manual training. In 1889, commercial electric lighting was only about 9 years old, the telephone about 14 years old, and the electric trolley car about 5 years old. Long-distance electric transmission was hardly contemplated; the X-ray had not yet been discovered, nor had radio. Electronics was far in the future, and even the incandescent lamp and electric motor were still to go through a long period of development.

Ten years later (1899–1900) the graduation requirements in Electrical Engineering had grown to 130 hours credit. The thesis was no longer required, and the Electrical Engineering courses were no longer listed under Physics. They consisted of EE 1 (Primary and Secondary Batteries), EE 2 and 3 (Electrical Measurements), EE 4a (Dynamo Electric Machinery), EE 5 (Alternating Current Apparatus), EE 6 (Photometry), EE 7 (Design of Electrical Machinery), and EE 8 (Distribution of Electricity). The chief curricular change was the requirement for courses in Alternating Currents and for a course in Design. Very few elective courses in Electrical Engineering were offered at this time.

Another ten years later (1909–10), the required work in Electrical Engineering had jumped to 25 hours. The course in Primary and Secondary Batteries had been dropped entirely, but an elective course in Storage Batteries was offered. The course in Dynamo Electric Machinery had been expanded to include more work in alternating current motors and converters. A new course in Electric Generating Stations and Sub-Stations was required, and two courses (totaling 4 hours) in Telephone, Telegraph and Related Apparatus were included in the EE offerings. A required course in Electric Railways was added, as were several elective courses. Undergraduate credit could be obtained for research work, although such work was intended primarily for graduate students. The total number of hours required for graduation had risen to 140 hours.

The year before this (1908), Michigan decided to try its hand at a 6-year curriculum. The regular 4-year program was continued, but a student could take the longer course if he wished. In the 6-year program all the regular studies were still required, and the technical content in Electrical Engineering was slightly increased. A student took additional work in English, Mathematics, Mechanical Engineering, History, Philosophy, Geology, and Law, and also took much more elective work, mostly of a non-technical nature. In all, 210 hours were required for graduation. After a student completed 140 hours, the degree of Bachelor of Science in preparation for Engineering was granted. The second degree, Bachelor of Engineering, required 175 hours. Finally, after 210 hours, the student was supposed to become Master of Electrical Engineering (or Mechanical, Civil, etc.). This 6-year course looked good on paper but few students, if any, completed it. Through the years there has been constant pressure to increase the non-technical content of the engineering curriculum. Everyone agrees that the engineer should be a broadly educated man and many of us wish that we had five or six years to spend with a student. Repeated attempts have been made to lengthen the requirements for an Engineering degree to correspond with those for a Medical, Dental, and Law degree, but all have failed.

Just after World War I, the Department began to place a strong emphasis on the theoretical aspects of Electrical Engineering. This trend toward stressing theory and reducing the amount of practical and applied work began under Dean Parker and continues today. The course in Electric Railways and those in Telephone and Telegraph were changed from required to elective courses. The Power Plant course had been expanded to 5 hours, including work on the economics of power generation. An entirely new advanced course in Electro-Mechanics introduced the undergraduate to the complex operator j, the Fourier Series, both transient and steady-state solution of networks, and a start on transmission-line theory.

Between 1920 and 1930, Electrical Design went far toward becoming a highly scientific study of the principles underlying design. In the early days, design methods had been very crude, and design was an art rather than a science. But now attention was being given to such subjects as flux mapping and heat transfer. During this decade, Principles of Electricity and Magnetism became a notable addition to the programs. From the beginning this was a theoretical course in the study of electric and magnetic fields; through the years it has grown and multiplied into many courses in both the undergraduate and graduate curriculum. A course in radio appeared during the 1920s, as did a course in electronics. Both of these prospered and proliferated, in later years becoming important parts of the curriculum.

The 1930s began with the Great Depression, and enrollment dropped steadily throughout the decade. The budget was cut back correspondingly. In 1924-25 (a peak year), 84 students had graduated in Electrical Engineering; ten years later, only 47 graduated. In 1939-40 the number of BS degrees granted fell to 40. During this same time, however, there was a steady increase in the number of graduate students; by the end of the decade, 12-14 students per year were receiving MS or MSE degrees. During the entire decade, only seven students received the PhD or ScD degree in Electrical

Engineering. In 1938, a senior elective course in Industrial Electronics was offered for the first time, as were two graduate-level courses (Theory of Thermionic Vacuum Tubes and Gaseous Conducting Electronic Apparatus). During the Summer Session of 1937, the EE Department offered an 8-week Electronics Symposium program, presenting invited lecturers from industry and other universities on selected subjects. These programs were organized by Dow.

In 1937, an undergraduate course on Photoelectric Cells was offered for the first time. Illumination and photometry continued to be an important part of the curriculum throughout the 1930s and the 1940s, but during the 1950s interest in this subject declined and the number of courses offered was cut back sharply. Today, no courses in illumination are taught by the EE Department; they are taught instead by the University's College of Architecture and Design. The decline of interest in illumination and photometry has been more than offset in recent years by the rise of interest in modern optics. Stimulated by the development of the laser (a powerful coherent source of light) and also by the application of holography to engineering problems, optics is undergoing a resurgence in the EE Department.

Television was first offered as a course in 1937. The first course in servomechanism was organized by Gault in 1944 as part of the University's ASTP program. In this course, the fundamental theory of closed-loop systems was presented to armed service trainees; a coordinated laboratory demonstrated practical applications.

The World War II years were probably the most trying in the history of the EE Department. Instruction had to be furnished to four different classes of students at the same time—civilians along with Army, Navy, and Marine trainees. The Naval and Marine students were on a program of 17 weeks per term; these corresponded to the Department's regular terms, except that there were three of them per year. The Army ran on four terms of 12 weeks each per year. A temporary loss of staff members to war research positions added to the problems of teaching at Michigan during this time.

Immediately after the war, the undergraduate program in Electrical Engineering was split into two options: (1) Electronics Communication and (2) Machinery Power. The major differences between these two options came in the senior year. Students in Electronics Communication elected a 3-hour course in Transmission Lines and Filters, two 4-hour courses in Radio Communication, and could choose a 4-hour course in either Industrial Electronics or Electron Tubes. Students in Machinery Power took a 3-hour course in Civil Engineering, a 1-hour Heat Power Laboratory in Mechanical Engineering, 3 hours of Power Plants and Transmission Systems, a 4-hour course in Automatic Control Systems, and 2 hours of Illumination and Photometry. These two options ran from 1946-47 to 1957-58. After that time, probably because of the reduced enrollment in Machinery Power, the options were abandoned. The program was made the same for everyone, and students were given a greater choice of electives.

Many elective and graduate courses first appeared in the late 1940s and 1950s, as new staff members were added to the Department and brought their skills and experience with them to Michigan. Microwave Engineering and Radiation and Propagation are examples of courses stimulated by developments that took place during World War II. Two courses in network synthesis were introduced by Macnee early in the 1950s. The first EE course in computers appeared in 1952 under the title "Seminar in Computer Technology"; it was under the direction of N. R. Scott (EE Department) and of J. DeTurk and L. E. Kolderup (Willow Run Research Center, Engineering Research Institute). The planning and organization of this course is an example of great benefits to be derived from correlation between University research and instructional activities. During the early 1950s, the major instructional load in computers was carried by experts at the University's research laboratories, where extensive analog and digital computer facilities had been developed.

In 1950, H. J. Gomberg taught a course on "Nuclear Engineering Measurement and Instrumentation." The EE Department is proud to note that Gomberg became the first Chairman of the College's Department of Nuclear Engineering, and that William Kerr (who also started in the EE Department) became the second.

An 8-week symposium held during the summer of 1950 marked the first formal instruction in semiconductor electronics at Michigan. This symposium, organized by Dow, was taught by members of the Department's research and teaching staff and by invited outside lecturers. By 1970, semiconductors have been introduced in all electronics courses offered by the Department, and its courses in solid-state physics and integrated circuits have grown to a sizeable number.

During the past few years, many staff meetings were held within the different Departments of the Engineering College to study the problem of curriculum revision. To say that these meetings were lively and full of conflicting opinions would be an understatement; the one subject on which a faculty member is sure to speak out is the curriculum. All Departments of the College set up new programs in the light of the College's revised requirements (noted below), but the changes approved by the EE Department were the most complete. Almost every one of its undergraduate courses was changed from the ground up, and program advisors are still trying to figure out just where they stand after this earth-shaking experience.

The College's new requirements went into effect for freshmen in the Fall of 1968, and reduced the number of semester hours required for graduation from a minimum of 138 hours to a minimum of 128. The new program is distinguished by a number of important features, including a completely modernized sequence of 11 hours in physics, 16 hours of engineering mathematics, a freshman engineering course that includes an introduction to digital computing and graphical communication, and a group of engineering science courses in such fields as thermodynamics and materials. The number of hours in humanities and social sciences has been increased to 24 hours, including 6 hours of "Great Books" and 6 hours of Literature and Rhetoric.

For students in the EE program, a number of basic courses are now required: Resistive Network Analysis (2 hours), Dynamic Network Analysis (2 hours), Electronic Circuits (3 hours), Electrical Circuits Laboratory (2 hours), Electromagnetic Field Theory I (4 hours), Mathematical Methods of Systems Analysis (3 hours), and Mathematical Methods of Field Analysis (3 hours). The inclusion of two courses in electrical engineering mathematics is intended to overcome a problem that had grown serious. Under the old program, a great deal of mathematics was being taught piecemeal in various EE courses. There was a tendency for this instruction to be repetitive; the same subject would receive several exposures in different classes but not much "depth exposure" in any. The new mathematics courses for EE students will be taught jointly by the Mathematics and EE Departments, and should eliminate this undesirable situation.

The courses noted above make up a package that is taken by all EE students. Beyond that, the curriculum is split into three options:

Option 1, ELECTRONICS AND DESIGN;

Option 2, ELECTRICAL SCIENCE; and

Option 3, COMPUTER, INFORMATION AND CONTROL ENGINEERING.

The student is given his choice of options, with the requirements listed below. This division of the curriculum is simply in recognition of the tremendous range of work now covered under Electrical Engineering, and the need for some specialization even at the undergraduate level.

Option 1, ELECTRONICS AND DESIGN, is what most of us associate with traditional Electrical Engineering. Most students who choose this option are likely to seek industrial experience upon graduation, although these students are as well prepared for graduate school as the students enrolled in the other two options. The option includes Energy Control I (3 hours), Principles of Physical Electronics (3 hours), Physical Electronics Laboratory (2 hours), Electrical Measurements (3 hours), and Electrical Design (3 hours).

Option 2, ELECTRICAL SCIENCE, emphasizes those aspects of electrical engineering that have as a foundation Maxwell's equations and quantum mechanics. A graduate of this program will be particularly well prepared in modern field theory, including radiation, optics, and quantum electronics and devices. Since these subjects can be pursued most profitably in depth, the best students in this program are expected to continue their studies at the graduate level. Courses in Option 2 include Electrodynamics (3 hours), Physical Electronics (3 hours), Physical Electronics Laboratory (2 hours), Electromagnetic Field Theory II (3 hours), Physical Electronics II (3 hours), and either an Electromagnetic Field Laboratory (2 hours) or an Integrated Circuits Laboratory (2 hours).

Option 3, COMPUTER, INFORMATION AND CONTROL ENGINEERING (CICE) combines three relatively new areas of electrical engineering that are growing very rapidly in importance as well as in student interest. A number of leading schools have developed undergraduate programs in computer science; however, many of these programs are too limited in scope to appeal to the electrical engineer. At Michigan, an attempt has been made to design a program in which the study of computer systems is better balanced against the study of communication and control systems. The complementary treatment of these subjects within a single program is believed to be an important source of strength. This belief was an important factor in the College's creation of a graduate program in CICE. The Departments of Electrical Engineering, Aerospace Engineering, and Industrial Engineering participate jointly in CICE, and the EE Department's Option 3 is intended to prepare its undergraduates for admission to this program. Courses taken by a student in Option 3 include Introduction to Linear Systems and Control (3 hours), Control Systems Laboratory (2 hours), Digital Computer Engineering (4 hours), Digital Computer Laboratory (2 hours), and Communication Signals and Circuits (3 hours).

In any one of these three options, the electives total about 30 hours; therefore students have a much greater choice of electives than they had under former programs.

At this date, more than 100 courses are listed under Electrical Engineering in the College ANNOUNCEMENT. On scanning them, one cannot help but be impressed by the dynamic nature of the field and the basic strength of the curriculum. No longer do we go for a decade with only a few minor changes. And what a long way we've come from batteries, dynamo machinery, distribution, and photometry!

III

EE RESEARCH

Research in the EE Department falls into three more or less distinct periods. Before the middle 1920s, it was carried out mostly on an individual basis, by faculty members and their student assistants. In 1920 the Department of Engineering Research (a University unit that has experienced several changes of name) was established as a formal administrative office to handle contract research. This unit made it convenient for groups to work on industrially sponsored projects under faculty direction. The scientific resources and laboratories of the University were thus made available to industry, and both faculty and students benefited by the increase in research opportunities. During the third period (from the middle 1940s to the present time), a large volume of government-sponsored research, particularly in the electronics field, has been added to the industrially sponsored research. Large laboratories have tended to form around of nucleus of permanent research personnel and faculty. Many students have been involved, especially those who are working on project-related PhD theses.

The beginning of significant research in electrical engineering at Michigan may be said to date back to 1875. In that year John W. Langley met Charles F. Brush, and their discussion of arc-lamp generators resulted in independent studies of the problem. Soon both Langley and Brush and built a successful arc-lamp generator of the series type; both generators were far superior to the others then in use. Brush's most important work proved to be 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 Patterson in electrical measurements. Patterson's work in the measurement of insulation resistance was particularly notable. Other Michigan men of this period who deserve mention are Frank C. Wagner for his mathematical analysis of motor design; Edwin H. Cheney for a study of temperature rise in copper conductors; Eleazer Darrow for his work on the economics of a double trolley railway system; Charles G. Atkins and Edward D. Wickes for their study of the measurement of power in alternating current circuits; and Sergius P. Grace for his study of the fundamental characteristics of telephone circuits.

From 1900 to 1910, Ray P. Jackson, Edward A. Weiland, and Oswald W. Visscher studied the properties of aluminum valve rectifiers. Harold Gillespie investigated the efficiency of charging batteries from 3-phase alternating current through a rectifier, and Adolphus M. Dudley made elaborate studies of induction motors.

Beginning about 1900, many research projects were carried out by Benjamin F. Bailey; the most outstanding were the 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 early 1920s, the Detroit Edison Company came to the conclusion that the small motors used on refrigerators, washing machines, oil burners, and other household appliances left much to be desired. The Company authorized a research program in the EE Department to determine the facts and provide a remedy. Covering two years (1923-25) and carried out by Bailey and several staff members, this project resulted in the invention of the capacitor motor and its development in commercial form. Since then, millions of these motors have been manufactured; today they are the most common form of single-phase AC motor. Royalties on the patents held by Bailey were an important source of revenue for the Department for many years.

Gault made important contributions in alternating-current machinery; his outstanding work, "Rotor Bar Current in Squirrel-Cage Induction Motors," was published in 1941. Through consulting and work in engineering design and development, he also made important contributions in servomechanisms and in the electric utilities field. Among his chief projects were checking the electrical equipment design of the Detroit and Windsor Tunnel, and the design and layout of two hydroelectric stations.

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

From 1928 to 1932 the National Electric Light Association sponsored a major group-research project relative to wind-produced stresses in wood pole lines and the pattern of wind gusts; this project involved extensive instrument design and field operations, and voluminous data reduction. [All this was before the day of computers, too!] Stout, Gault, and Dow made major contributions.

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 emphasis on electro-magnetic wave propagation. While on leave of absence during World War II, Attwood 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 in wave propagation, his outstanding contribution being the compilation and editing of a three-volume summary report of the committee's work.

Between 1924 and 1932, Moore conducted successful studies of (1) the quantitative graphical methods for determining the flux and equipotential maps of two-dimensional electrostatic, magnetic, and elastic stress fields, and (2) 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 permitted completely quantitative studies to be made 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.

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 A. Bychinsky and John A. M. Lyon, whose theses grew out of illumination problems. Lyon later served as Chairman of the EE Department at Northwestern University and joined the staff of Michigan's EE Department in 1959. His current research is in the area of antennas. Higbie's most notable contributions to the study of lighting occurred between 1924 and 1941. In various papers published in the ILLUMINATING ENGINEERING SOCIETY TRANSACTIONS, he put the design of natural lighting of interiors on a scientific basis.

In the late 1940s, Dow initiated an investigation of the use of high-frequency power for welding sheet metal. This work, sponsored by GM's Fisher Body Division and carried out under Dow's direction by research and graduate students, resulted in a number of patents. Harold C. Early participated in this research and later became director of the Department's Plasma Engineering Laboratory.

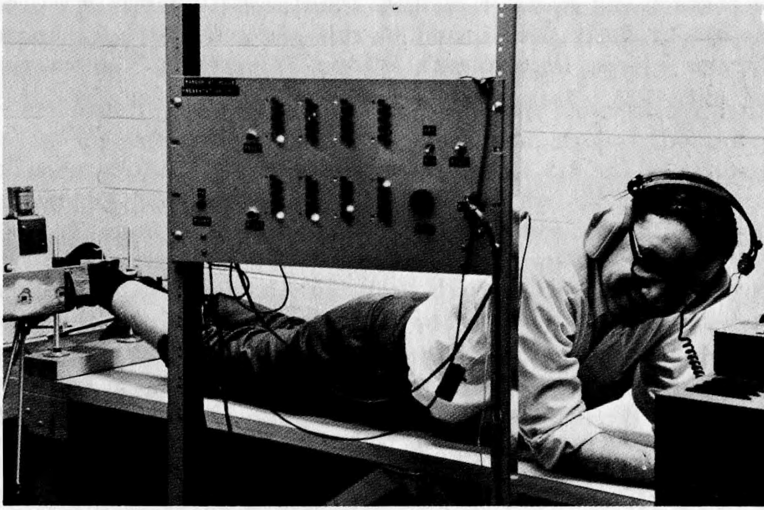
After World War II there was tremendous growth in the amount of sponsored research carried out by the EE Department for various agencies of the US Government. In 1945 Dow and Emerson W. Conlon, then Chairman of the College's Aeronautical Engineering Dept., initiated negotiations with the Air Force for research in the rapidly opening "guided-missile" area. The EE Department's initial involvement in this research dealt with instrumentation installed in V-2 rockets to measure temperature and pressure of the upper atmosphere; this was the beginning of what is now called the Space Physics Research Laboratory. In similar fashion, usually with Dow as entrepreneur, various other research laboratories were established within the Department, each with its own responsible director. These laboratories had relatively modest beginnings, with initial contracts set at $50,000–$150,000 a year; gradually, however, the support increased and the laboratories thrived.

A brief description of the current Departmental laboratories follows.

BIOELECTRICAL SCIENCES LABORATORY

The Bioelectrical Sciences Laboratory was organized in 1968 and represents the EE Department's activity in the Bioengineering Program. The Laboratory is involved primarily in engineering-oriented studies in electrophysiology and neuropsysiology. The present research program is directed toward studies of transducer properties and coding in receptor organs, activation and control

Some of the research at the BIOELECTRICAL SCIENCES LABORATORY is focused on mathematical models of eye and leg movement. This equipment, of particular interest in highway safety, yields data that are useful for diagnostic purposes and for the prediction of behavior.



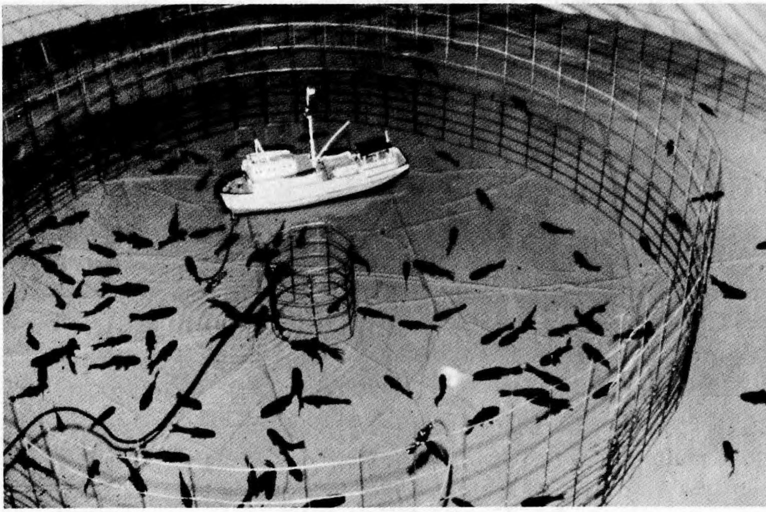
of skeletal muscle, the conglomerate behavior of large networks of sensory and motor elements, and the electrical properties of biological tissue.

At present, several doctoral students are completing their degree work in this Laboratory, and three new faculty members with joint appointments in Ophthalmology, Pediatrics, and the Kresge Hearing Research Institute were added to the staff in 1969. The number of participating faculty members, staff, and graduate students now total 17; Professor William J. Williams is Director.

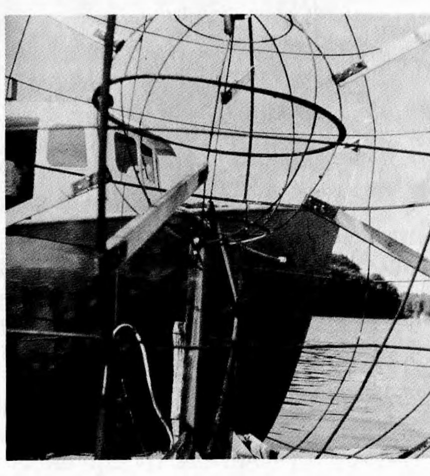
COOLEY ELECTRONICS LABORATORY

The Cooley Electronics Laboratory is the outgrowth of the Electronic Defense Group formed in 1951 by Professor Dow. This Group was organized to do research in electronic countermeasures under sponsorship of the US Army Signal Corps. The group was originally located in the East Engineering Building; in 1953 it moved to the Mortimer E. Cooley Building—the first building on the University's North Campus.

In 1960 the Electronic Defense Group was renamed the Cooley Electronics Laboratory to reflect a growing diversity of research work. At present, the Laboratory conducts research in six major program areas: Acoustics-Optics, Communications, Information



One research project at the COOLEY ELECTRONICS LABORATORY, devoted to electro-fishing, is aimed at modernizing the commercial fish industry. Through installations in the Lab's test pools and on board a boat, new ways of "catching" fish are being studied.



Processes, Instrumentation, Solid-State Circuits, and Industrial Sciences. The Laboratory still maintains a strong effort in electronic countermeasures, however, with support from all three military services. For 18 years, the Laboratory has had a continuous relationship with the US Army (Fort Monmouth)—a fact that provides some measure of the Laboratory's continuing performance and capability.

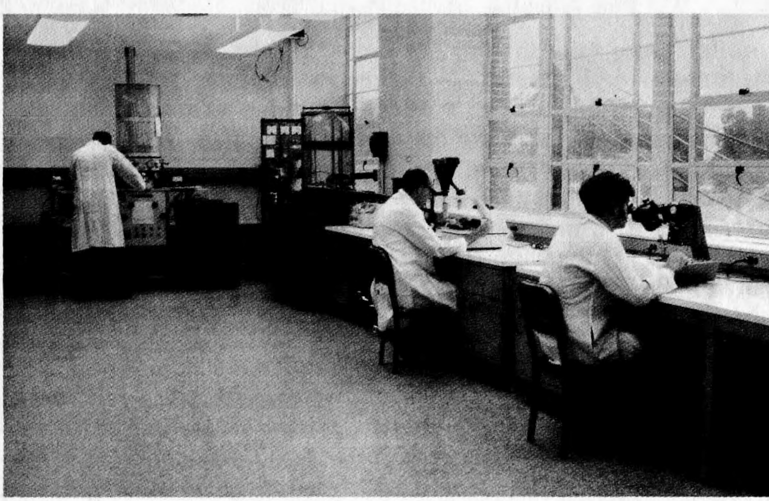
Probably the Laboratory's greatest achievement is its success in doing distinguished research with extensive student participation. Since 1951, no less than 37 students have received PhD degrees based upon research work supported by the Laboratory. Currently 16 students are engaged in thesis research, and another 12 are participating in research activities.

The success of the Laboratory is largely attributable to a succession of strong and highly competent leaders. Professor W. G. Dow was its first director, and when he became Chairman of the EE Department in 1953, Dr. Homer W. Welch, Jr. was promoted from Project Engineer to Head of the Group. Bill left the group in 1955 and subsequently became a Vice-President of Motorola in Phoenix, Arizona; he is now Associate Dean of Engineering at Arizona State. Joseph A. Boyd succeeded Welch and headed the Group until December 1957; he then became Director of the Willow Run Research Laboratories and later President of Radiation, Inc., in Florida. Professor Harry Goode took over for Joe Boyd in January 1958 on an interim basis until a new director was appointed. Professor Hansford W. Farris was Director of the Group and of the Laboratory from September 1958 to June 1961. He later became Chairman of the EE Department, and is now Associate Dean of the College of Engineering. Professor Ben F. Barton served as Director of the Laboratory until June 1965, when he became a Technical Advisor to NATO in Paris, France. He has now returned to active teaching and research in the Department. The present Director, Thomas W. Butler, Jr., was associated with the Laboratory as a student project engineer, and Assistant Director since is founding in 1951. After receiving his PhD, he became Director of Engineering for Mechanical Products, Inc., of Jackson, Michigan, and returned to head the Laboratory in 1965.

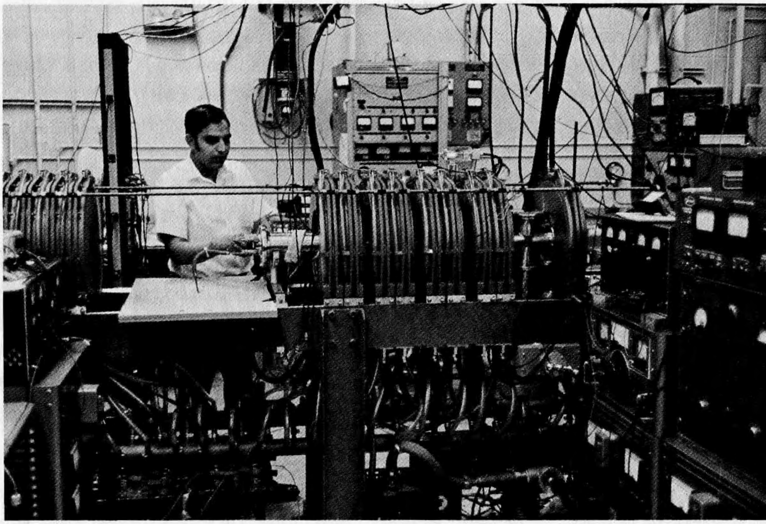
Over the years, a few groups within the Laboratory grew large enough to form their own organizations. Among these were the Sensory Intelligence Group under Professor Wilson P. Tanner, and the Systems Engineering Group under Professors Arch W. Naylor and Keki B. Irani. Several outside companies have also "spun-off" from the Laboratory; G. C. Optronics, JoDon Associates, Transidyne Corporation, and Balance Technology, Inc., were all launched by former personnel.

ELECTRON PHYSICS LABORATORY

The Electron Physics Laboratory was organized by Professor Dow in 1946 as the Electron Tube Laboratory to conduct fundamental research in the field of microwave tubes. Early work of the Laboratory centered on frequency-modulated magnetrons and voltage-tunable magnetrons. This was later expanded to include traveling-wave amplifiers, theoretical and experimental studies of general electron interaction phenomena, plasma characteristics, solid-state devices such as masers, and parametric amplifiers.



New facilities at the ELECTRON PHYSICS LABORATORY include vacuum stations for thin-film studies as well as an ultrasonic bonder and a microscope camera. The second photo shows a solonoid magnet for beam plasma interaction studies, located on North Campus.



Beginning in 1958 under the direction of Joseph E. Rowe, the research program changed markedly from one primarily concerned with microwave tubes to one primarily concerned with solid-state devices and plasmas. At the same time, the Laboratory was renamed the Electron Physics Laboratory to indicate this change in emphasis. Since the Laboratory was first founded, a large number of graduate students and EE staff members have participated in its work.

The Laboratory's research, conducted with Signal Corps support, was concerned with frequency modulation of interdigital magnetrons; a number of magnetrons were constructed and tested with power outputs near 500 watts cw and operating efficiencies ranging from 50 to 75 percent. Jules S. Needle obtained a low-power voltage-tunable magnetron with a wide tuning range. Joseph A. Boyd advanced the development in 1953 with a magnetron that was connected across a rectangular waveguide as the anode circuit; further improvements were made by Gunnar Hok, who proposed the use of a right elliptic cylinder as the external cavity.

Early in 1953, the US Navy Bureau of Ships sponsored the Laboratory in a research and development program involving a high-power cw traveling-wave amplifier. The result was a tube that used a helix r-f structure and a power of over 100 watts in the band 2500 to 3500 mHz. The large-signal theory of a traveling-wave amplifier was worked out by Rowe, who also developed the crestatron, a new type of microwave amplifier which has several advantages over the conventional traveling wave amplifier.

Starting in 1954, the Laboratory initiated research on the Carcinotron, a voltage-tunable device which operates on a backward wave and uses crossed DC electric and magnetic fields. Murray H. Miller contributed extensive theoretical and experimental studies to this program. Members of the Laboratory staff (particularly Robert J. Martin and Rowe) developed a Poisson cell and analog computer system for the design of electron injection systems; this system has now been delivered and installed at the US Army Electronics Command Laboratories at Fort Monmouth.

Rowe served as Director of the Laboratory from 1958 to 1968, when he became the Chairman of the EE Department. George I. Haddad is the current Director; the Laboratory's principal areas of research today are concerned with Gunn effect devices, avalanche diodes, and solid-state plasma phenomena. Approximately 22 graduate students and a supporting staff of 12 are involved in its research.

PLASMA ENGINEERING LABORATORY

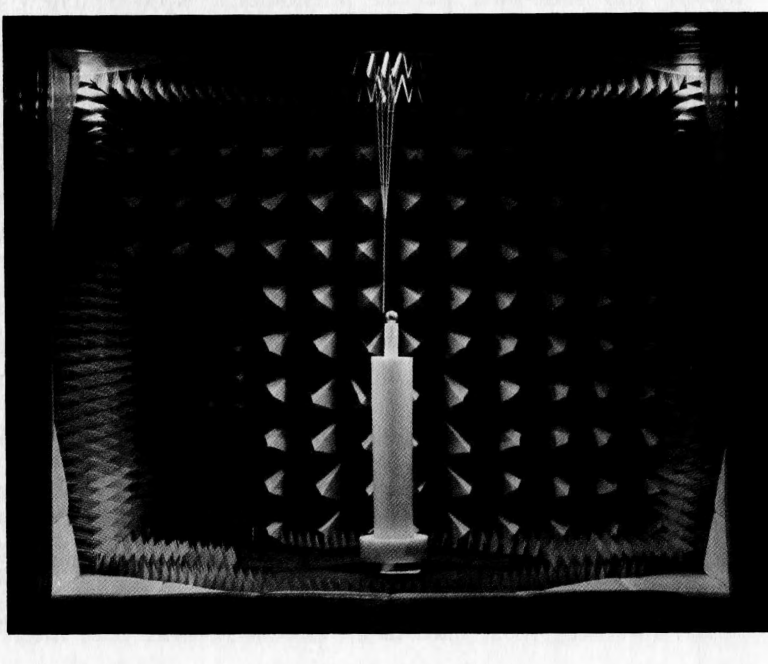
The Plasma Engineering Laboratory is concerned with engineering applications of high-pressure, high-temperature plasmas. Typical research projects involve "hot shot" wind tunnels, hypervelocity plasma-propellant guns, and arc jets for growing crystals of refractory materials. Often the experiments involve transient currents of hundreds of thousands of amperes. Now located in the Fluids Building on the North Campus, the Laboratory was formerly located on the second floor of the East Engineering Building. Harold C. Early is Director of the Laboratory; a number of students and EE faculty members have been associated with it—Edward A. Martin in particular.

The Plasma Engineering Laboratory has been eminently successful over the years in applying its work to the practical solution of engineering and industrial problems. At one time it developed a high-speed "spark punching" process for punching holes in paper. Punching took place in an extremely short time interval (about 3 microseconds) and could be accomplished on paper traveling at speeds up to 250 feet per second. Many of us recall the noise produced by this ingenious operation. It was not unlike the sound of a rapid-fire machine gun!

The Laboratory built one of the largest energy storage inductors ever built—a mile of 2-inch aluminum cable weighing 15,000 pounds and capable of storing 3 million watt-seconds of energy. When this energy is released suddenly, the noise produced is best described as an explosion. In fact, the Laboratory was often referred to as "the big bang laboratory." After what sounded like a catastrophic explosion, many a nearby student or faculty member has rushed in expecting to find a chaos of wounded scientists and blown-up equipment, only to find everything in perfect order.

RADIATION LABORATORY

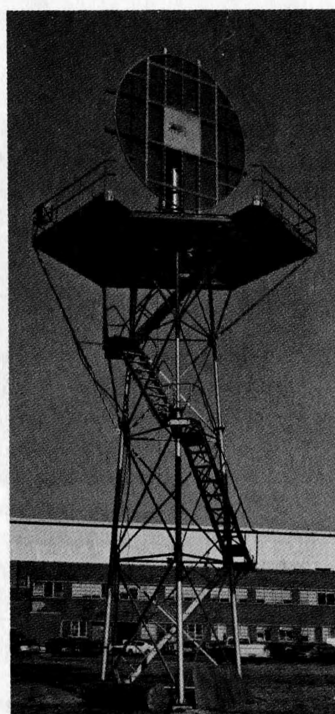
The Radiation Laboratory, formed in 1948 as the Upper Atmospherics Physics Group, was originally part of Michigan's Aeronautical Research Center. At this time it was headed by Professor



Charles L. Dolph and located at the Willow Run Airport. Shortly after Keeve M. Siegel was made head of the Group in 1952, it became the Theory and Analysis Department. Most of the Group moved into Ann Arbor in 1958; since 1959, it has been located at 201 Catherine Street. During the course of these moves, the Group became part of the EE Department, and had been renamed the Radiation Laboratory.

The Laboratory's major areas of interest are the study of radar cross-sections, scattering, diffraction, antennas, and propagation. Professor Dow aptly characterized the group as being concerned with the radiation and propagation of electromagnetic energy and its interaction with anything in its path. These studies were a first largely theoretical, but since 1958 the theory has been supplemented by a vigorous experimental program. Experimental facilities have been developed not only at Willow Run but on North Campus, currently in the George Granger Brown Building.

The RADIATION LABORATORY maintains a tapered anechoic room with a surface-current measurement facility shown in the first picture. The second shows a "rudimentary horn antenna" mounted by the Lab as receiver on a 45-ft. tower at the Willow Run Test Range.



The Laboratory staff presently numbers about 40 people, about half of whom are students (mostly graduate students). The other half is about equally divided between part-time teaching faculty, full-time professional research personnel, and supporting staff. Since 1961, Professor Ralph E. Hiatt has been Head of the Laboratory, and Professor Thomas B. A. Senior has been Associate Head.

SPACE PHYSICS RESEARCH LABORATORY

The origins of the Space Physics Research Laboratory date back to 1946, and the history of its growth parallels that of the nation's space program. Professor Dow founded the Laboratory to carry out research initially funded by the Air Force; he was a charter member of the V-2 Rocket Panel, a group of distinguished scientists and engineers who guided the nation's space program through its infancy. The first research activity consisted of measurements of the earth's upper atmosphere with instruments conceived and constructed by the Laboratory and flown on captured V-2 rockets.

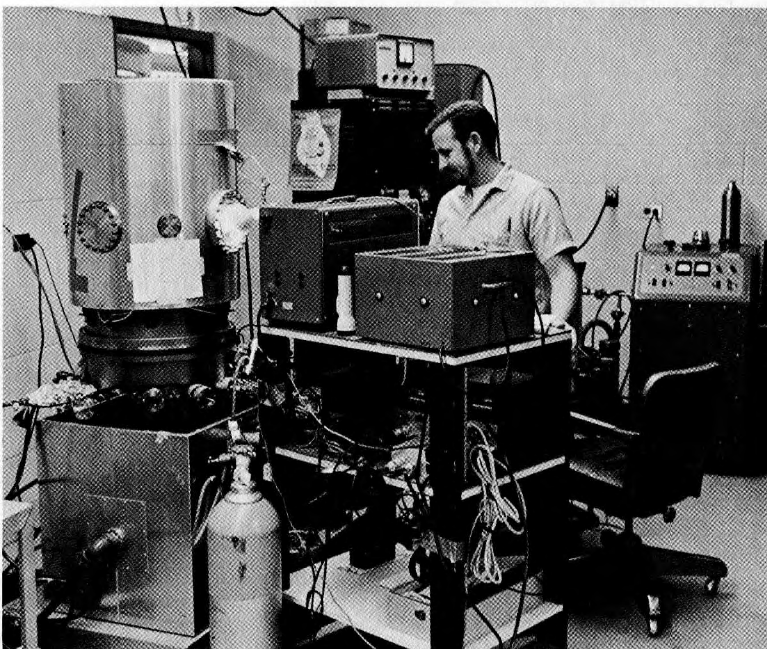
One of the early staff members, Professor Nelson Spencer, became Director of the Laboratory in 1951. Spencer was made a member of the Rocket and Satellite Research Panel, which planned the nation's space program in the decade of the 1950s (including the US program for the International Geophysical Year). The Laboratory instrumented some 15 rockets which were launched from Fort Churchill, Manitoba, Canada, in 1957 and 1958 as part of the IGY program.

The three measurement techniques developed for the IGY program are still, in updated form, the mainstays of the Laboratory's experimental research. Among the three is an electrostatic probe system for measuring the temperature and density of ionosphere electrons. Measurements made by these probes showed, for the first time, that the temperature of electrons in the ionosphere exceed that of the neutral gas. This significant discovery had important implications in the theory of atmospheric physics, and served to propel the Laboratory to the forefront of geophysical research.

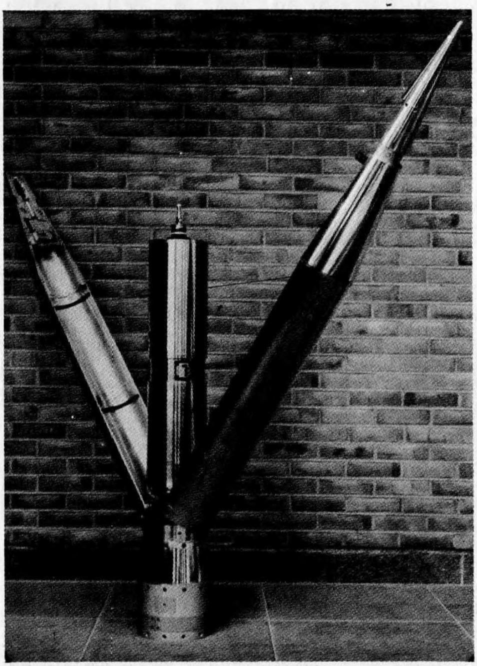
Shortly after the National Aeronautics and Space Administration was formed, Professor Spencer moved on to Washington, D.C., to take on increased responsibilities in the space program. Mr.

Larry Brace served as Director for about one year before following Professor Spencer to NASA. He was succeeded by Mr. George R. Carignan, who continues to serve as Director. In recent years the scope of the Laboratory programs has broadened; about 50 students are currently engaged in Laboratory research programs.

The Laboratory's accomplishments and output have included a few hundred papers and reports, a few dozen well-trained PhD's, and many accomplished student graduates with lesser degrees.



At the SPACE PHYSICS LABORATORY, a graduate student conducts surface contact potential studies in a vacuum. The second photo shows a nose cone with an outer shell that opens at 70km altitude to deploy an inner, data-gathering cylinder.

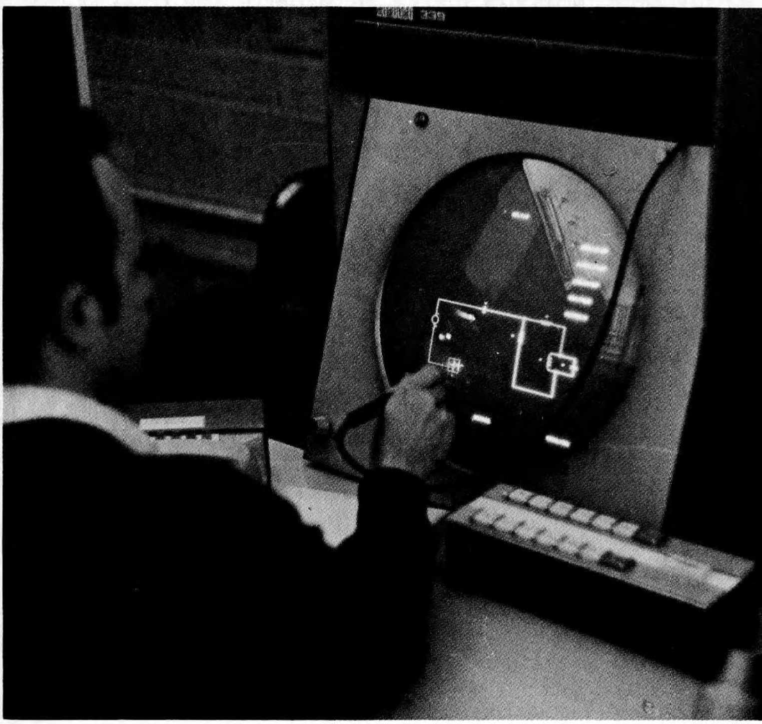


The Laboratory has served as a successful springboard for a new company, a company president, a congressman, and a large number of competent scientists and engineers widely dispersed in industry and universities. Its membership has included prominent scientists from Europe and Asia and well-known professorial members of the Departments of Mathematics, Physics, Nuclear Engineering, and Electrical Engineering.

SYSTEMS ENGINEERING LABORATORY

The Systems Engineering Laboratory was formed in 1965, bringing together staff and facilities in the fields of automatic control, communications, computers, and information and energy systems. The organization of the Laboratory is somewhat unique in that the chairmanship changes on a rotating basis each year. Men who have served as chairman are: Norman R. Scott, Harvey L. Garner, Eugene L. Lawler, William A. Porter, Arch W. Naylor, and Donald A. Calahan. Currently, Edward D. Sybesma is the Laboratory's administrative assistant.

On the 2nd floor of the East Engineering Building, the Laboratory maintains analog and digital computer facilities as a resource for both research and instruction. Many graduate students working on doctoral research are employed on a part-time basis by the Laboratory. A few examples of research projects undertaken are as follows: Design Techniques for System Sensitivity Reduction, Real Time Computer Recognition of Symbols and Characters using Directional Information, Discrete Control Synthesis (for the National Science Foundation); Reliable Spacecraft Data Systems (for the Caltech Jet Propulsion Laboratory); Computer-



The SYSTEMS ENGINEERING LABORATORY has a PDP–9/339 computer linked by telephone lines with the U–M Computing Center. The PDP–9/339 is used primarily for computer-aided design.

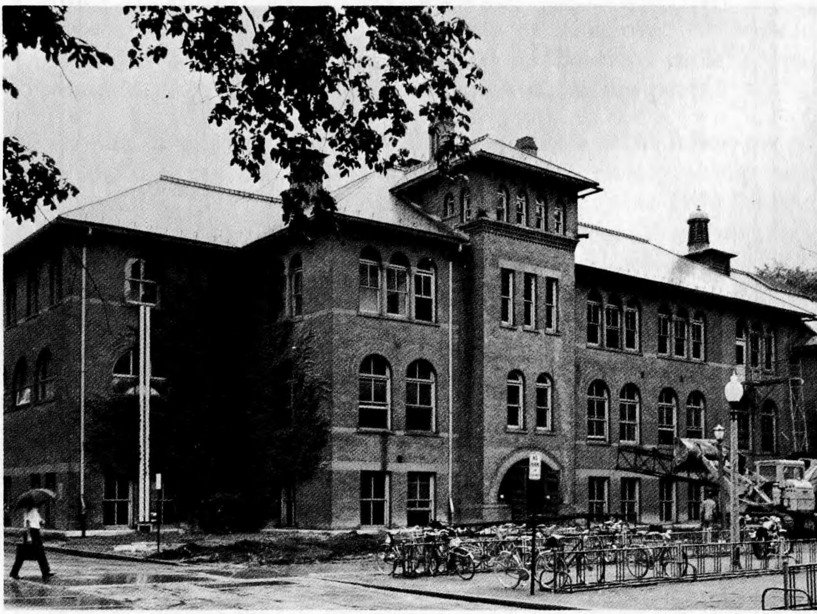
Aided Power Systems Planning (for Consumers Power Co.); Mathematical Techniques for Analysis and Design of Computer Systems, Mathematical Models of Information Processing Systems (for the Rome Air Development Center); Graphical Language-Computer Communication, The PORTATERM Development Project (for the Advanced Research Projects Agency). The PORTATERM project is a relatively inexpensive system that uses analog drawing devices operating at a remote location over voice-grade telephone lines; one of the potential applications most appropriate for this system is the transmission of picture parts.

From this brief history of the EE Department and its laboratories, it is clear that research has grown from very modest beginnings into "big business." For example, during the academic year 1969–70, the Department operated a sponsored research program of approximately$3.8 million. Both students and faculty members benefit from this contact with the frontiers of science and industry, and the Department is indeed proud of its research achievements.

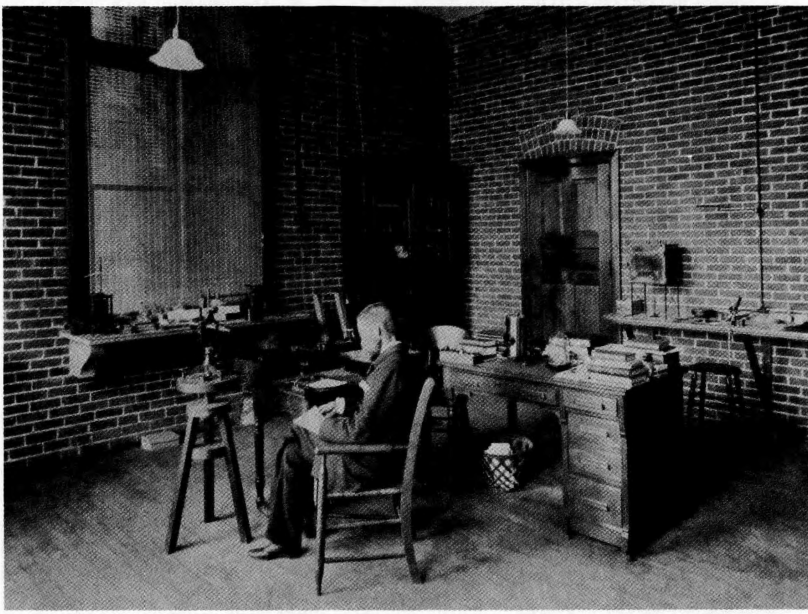
IV

AN EE PHOTO FOLIO

Tucked away here and there in Departmental files are odd photos that move old grads to nostalgia and/or laughter. Here, to stimulate one or the other or both, is a sampling.

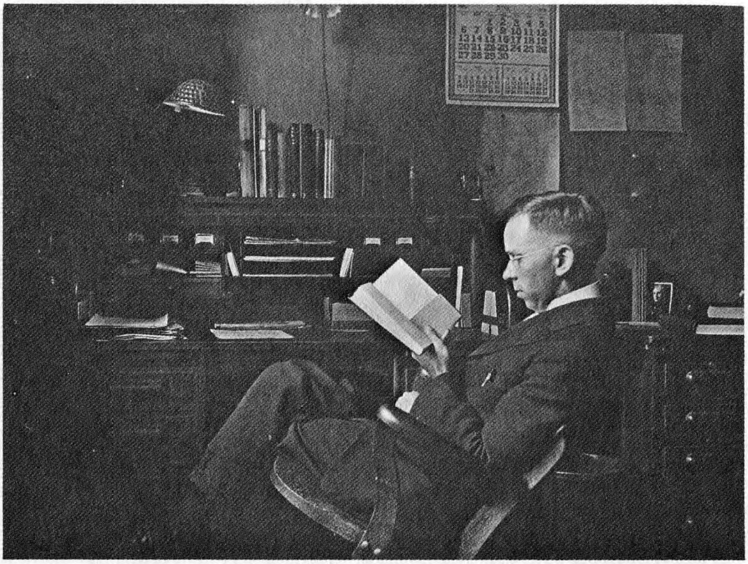


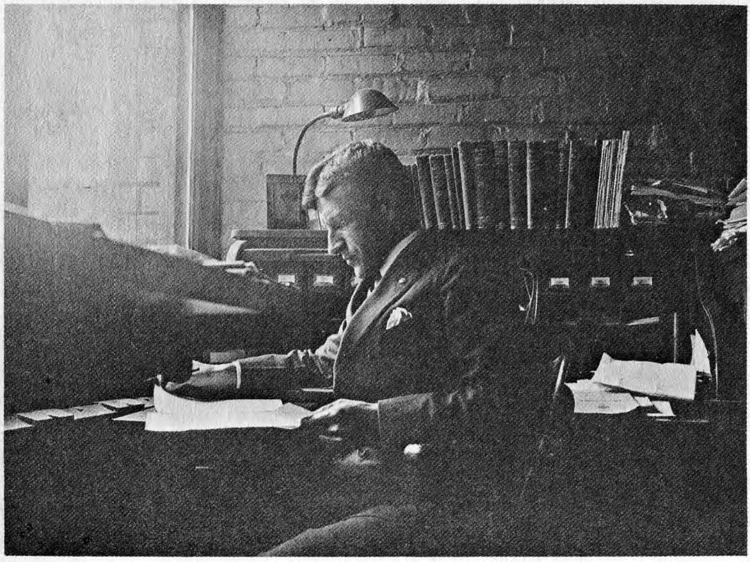
The Department's "birthplace" was an electrical lab located in the Physics Laboratory's east basement room (shown here behind the umbrella). This photo was taken in 1967, just as the wreckers were moving in. By the way, the old building didn't go gently. Although it had survived countless short circuits and sparks, it went up in flames at the mere touch of a wrecker's cutting torch.



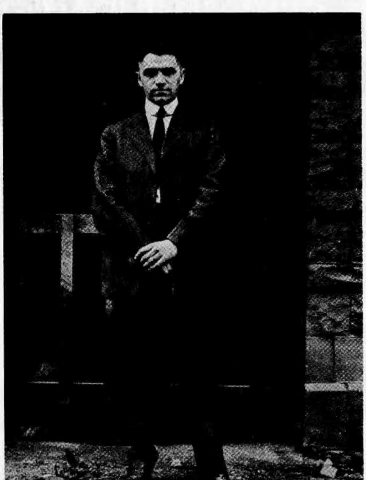
Professor Carhart in his lab/office in the old Physics Lab. The year is probably 1893, when the Columbian Exposition was the big thing in Chicago. Carhart went there to read a paper to the International Electrical Congress, describing the electrostatic voltmeters he had designed—one of which can be seen on the window shelf, another on the desk.

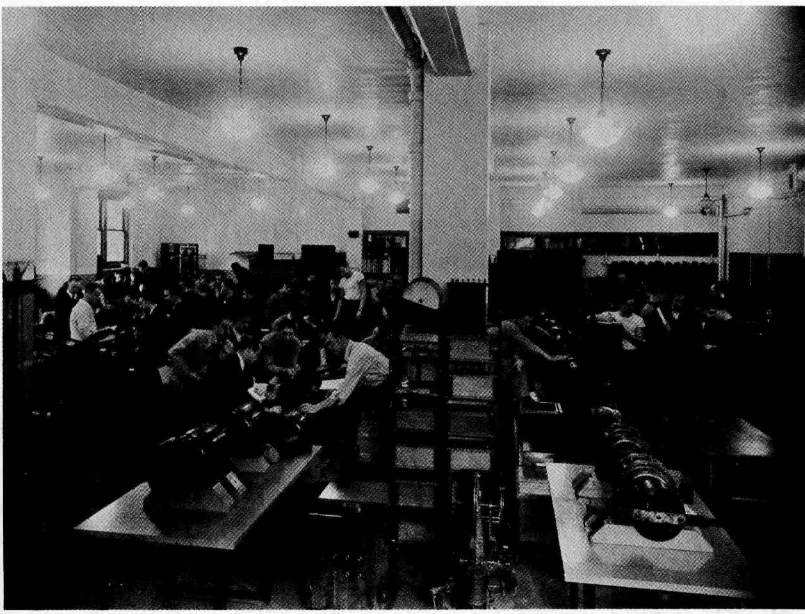
A. D. Moore took these remarkable portrait studies of early colleagues—in order: BENJAMIN BAILEY, JAMES FAIRMAN, PORTER EVANS, and ALFRED LOVELL.



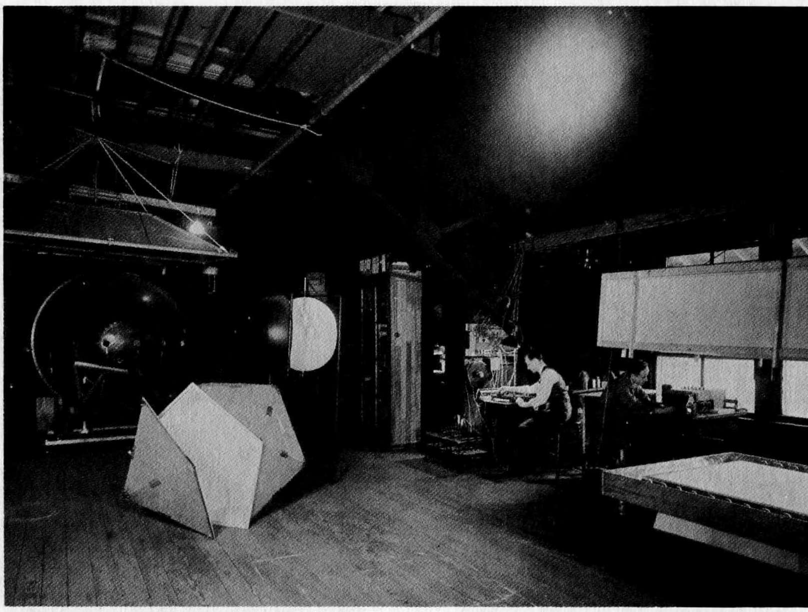


The photographer himself — A. D. MOORE, looking dapper on the roof-top. Below, 'ENRY 'AROLD 'IGBIE, a transfer from Mechanical, and EDWIN BLYTHE STASON, a transfer out of engineering into—eh—law.





The Department had facilities high and low in the West Engineering Building. The Dynamo Lab (the Department's main lab facility from 1910 until 1947) was low down, in the north end of the basement. The sailors in this photo suggest that it was taken during World War II.



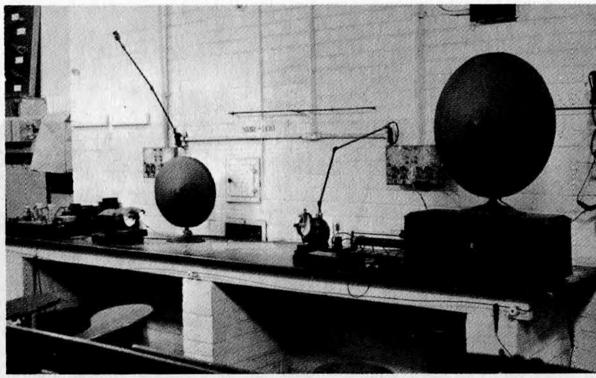
The Photometric Lab was stashed high up in the West Engin attic. This shot was taken during the heyday of photometry, long before research interest had been diverted from it to modern optics.

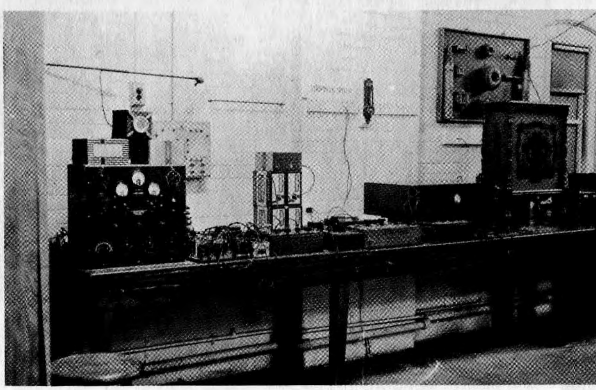
Thanks partly to the Depression economy, the Department enjoyed almost total stability in staffing during the 30s. Except for an instructor who fell victim to the budget squeeze, this same rouges' gallery could have served for any year from 1926 till 1942.

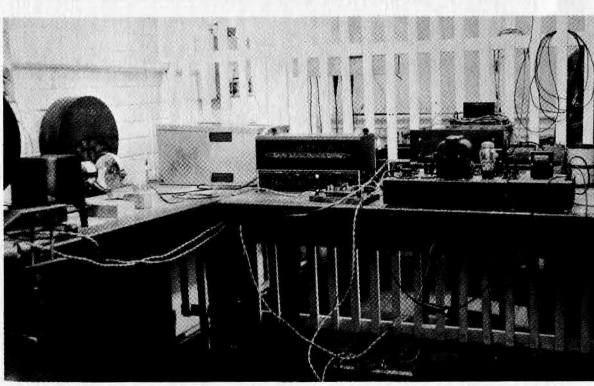
The Department has been sponsoring picnics for a long time; here are shots from a couple. The first, taken about 1922, was a full Departmental affair, as is obvious from the presence of wives and kiddies.

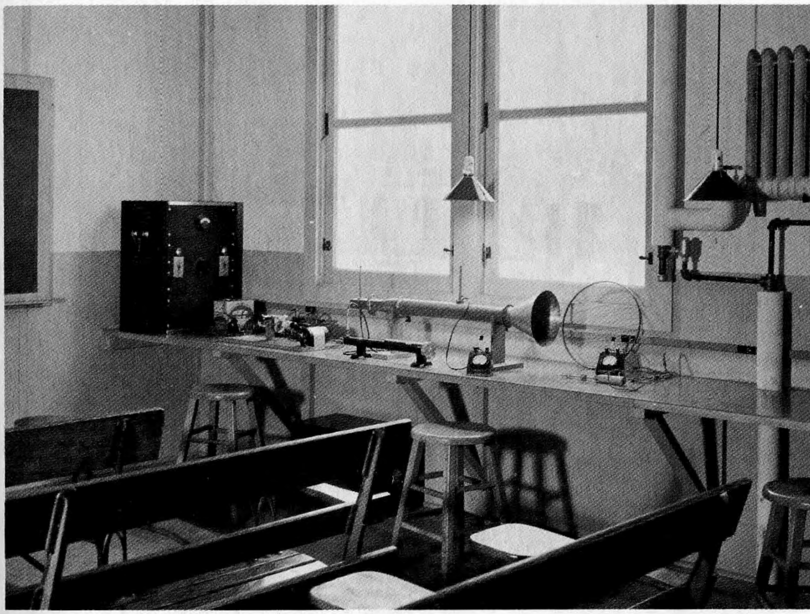
This second picnic shot, taken at Whitmore Lake not long after World War II, shows an almost-stag AIEE-IRE outing.

Here are three equipment shots that show random hot projects of 1937. The first carries a legend, "Sound on Light"; the second, "Scrambled Speech"; the third—hold on to your hats!—"Television."





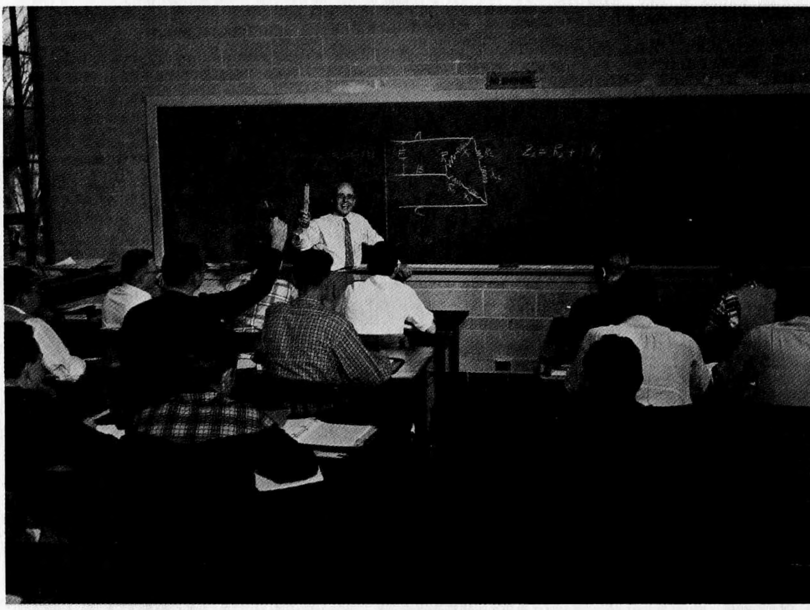




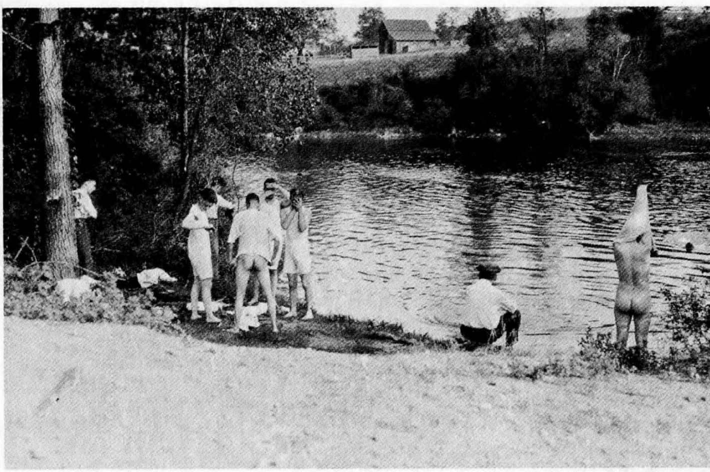
For a few years during and after World War II, EE classes and labs were squeezed into a temporary building next to the Diag and close to the Arch. Here is some of the first waveguide and microwave equipment at the U–M.

In the late 40s and early 50s, the staff bulged along with enrollment figures. One staff addition was the author of this history; here he is, with the halo he wore in 1951 by way of anticipation.

Two elder statesmen of the Department (Lovell and Bailey) examine an early model of the Brush arc lamp.



A typical classroom scene from the south wing of East Engin, still the Department's home. The subject seems to be a 3-phase delta connected load; the jolly instructor is (for sure) Hempy Bull.



EE gad, staff members skinny-dipping in the Huron! Great shades of the past, what won't they think of next.

APPENDIX A: EE FACULTY MEMBERS (1970–71)

PROFESSORS
Barton, Benjamin F.
Brown, Richard K.
Brown, William M.
Carey, John J.
Chu, Chiao-Min
Chuang, Kuei
Farris, Hansford W.
Grimes, Dale M.
Haddad, George I.
Hellwarth, Arlen R.
Hiatt, Ralph E.
Hok, Gunnar
Irani, Keki B.
Kazda, Louis F.
Lawler, Eugene L.
Leith, Emmett N.
Lyon, John A. M.
Macnee, Alan B.
McMullen, Charles W.
Mosher, Raymond F.
Mouzon, James C.
Naylor, Arch W.
Olte, Andrejs
Porter, William A.
Rowe, Joseph E. (Chairman)
Scott, Norman R.
Senior, Thomas B. A.
Sharpe, C. Bruce
Smith, Newbern
Tai, Chen-To
Weil, Herschel
Yeh, Chai

ASSOCIATE PROFESSORS
Birdsall, Theodore G.
Butler, Thomas W.
Calahan, Donald A.
Curtice, Walter R.
Diamond, Howard (Adjunct)
Enns, Mark K.
Getty, Ward D.
Lomax, Ronald J.
Martin, Edward A.
Masnari, Nino A.
McMahon, E. Lawrence
Nagy, Andrew F.
Nelson, Thomas J.
Porcello, Leonard J.
Williams, William J.

ASSISTANT PROFESSORS
Anderson, David J.
Bement, Spencer
Gelembe, S. Erol
Green, Daniel G.
Khan, Peter J.
Meyer, John F.
Owings, Clyde L.
Ribbens, William B.
Shabde, Sunil N.
Volz, Richard A.

LECTURERS
Aupperle, Eric M.
Barnett, Norman E.
Burkhalter, Kenneth E.
Carignan, George R.
Early, Harold C.
Fontheim, Ernest G.
Hemdal, John F.
Hoopes, Charles C.
Johansen, Elmer L.
Orr, Lyman
Raney, R. Keith
Zissis, George J.

PROFESSOR EMERITUS
Bull, Hempstead S.
Dow, William G.
Holland, Lewis N.
Martin, Edwin R.
Moore, A. D.
Stout, Melville B.

APPENDIX B: A CHRONOLOGICAL LISTING OF EE THESIS DEGREES

1929 Edwin E. Dreese/EE/Synchronous Motor Effects in Induction Machines
Wactaw T. Szymanowski/ScD/A Rapid Method for Predicting Daylight Distribution in Buildings

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1930 Walter Krausnick/PhD/The Re-Ignition of Metallic Arcs on AC
Burtis L. Robertson/EE/The Determination of Synchronous Machine Constants by Test
1931 Adolphus M. Dudley/EE/Induction Motor Practice
1932 Darl F. Caris/EE/An Electrical Engine Indicator and Some Practical Aspects of Resonant Shunt Damping of Oscillographs
Gregory S. Timoshenko/PhD/Potential Distribution in a Metallic AC Arc During the Re-Ignition Period
1933 W. Herbert Bixby/PhD/Time Lag in the Breakdown of Liquid Insulations as a Function of the Rate of Voltage Application
1935 Ernest J. Abbott/EE/The Measurement of Rear Axle Gear Noise on Test Stands
Charles Russell Burrows/EE/Ultra-Short-Wave Propagation. Mobile Urban Transmission Characteristics
Paul O. Huss/ScD/Circuit Analysis of the Copper-Oxide Rectifier
1936 John Melvin Lyon/PhD/A Study of the Design of Surface Sources of Illumination
1937 Arthur St. John Hill/EE/A Study of Fan Performance in the Cooling of Fully Enclosed Electric Motors
Shih L. Ma/ScD/Power and Efficiency Measurements at 60-Megacycles Per Second
Fred Schumann/PhD/High-Gain Amplifiers for Extremely Small Direct-Current or Audio-Frequency Voltages

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1940 John F. Lamb/ScD/An Investigation of the Peak, Average, and Effective Currents and Voltages Occurring in the Series Ferro-Resonant Circuit
1941 Lamar M. Kishlar/EE/An Investigation of the Effect of Short Wave Ultraviolet Irradiation Upon Bread Quality
Allen M. Perry/EE/History of the Evolution of Electrical Industry
Suvan T. Vadhana/PhD/The Effect of Superposition of Alternating Current on Direct Current in the Electro-Deposition of Chromium
1946 James M. Lafferty/PhD/The Analysis, Design and Construction of a Millimeter-Wave Reflex Oscillator
1947 George M. Chute/EE/Electronics in Industry
1948 Harry A. Romanowitz/PhD/Measurements, Analysis and Statistical Nature of Dionization Time in a Mercury Vapor Thyratron

1949 Lyman W. Orr/PhD/A Study of the High Frequency Structure of Spectral Light Intensity Produced by Spark Excitation Using Electron Multiplier Phototubes

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1950 Henry L. Byerlay/EE/Electronic Ignition Monitor

William R. Correa/PhD/An Investigation of Mode Duplexing in a Circular Waveguide

Jack F. Cline/PhD/An Antenna Impedance Measuring Instrument for Balanced, Unbalanced, and Irregular Terminals

Leonard W. Holmboe/PhD/A Traveling Wave Amplifier Design Using, as a Transmission Line, a Folded Waveguide Outside the Vacuum Envelope

Mi Lee/PhD/The Electromagnetic Fields Generated in Rectangular Cavities and Wave Guides by Various Types of Sources

Floyd Schultz/PhD/Scattering by a Prolate Spheroid

Jerome Weisner/PhD/Pre-Ignition Phenomena in Gas Switching Tubes and Related Rectifier Burnout Problems

1951 Shou-Hsien Chow/ScD/Theoretical Investigation of a Rectangular Resonant Ring in a Rectangular Wave Guide Transmitting TE_{10} Wave

Ibrahim H. A. El-Abd/ScD/Analysis of Fuel Sprays by Electrical Methods

Henry J. Gomberg/PhD/A High-Resolution System of Autoradiography

Warren D. McBee/PhD/A Study of the Influence of a Strong Transverse Magnetic Field on an Unconfined Glow Discharge in Air at about 1mm Pressure

Robert W. Olthuis/PhD/A Study of the Coupling Induced Between Two Modes in a Microwave Cavity by a Gas Discharge in a Magnetic Field

1952 George R. Brewer/PhD/The Propagation of Electromagnetic Waves in a Magnetron-Type Space Charge

Richard K. Brown/PhD/Measurement of the Velocity of Propagation of a Sound Wave in the Ocean as a Continuous Function of Depth

Chiao-Min Chu/PhD/Scattering and Absorption of Water Droplets at Millimeter Wavelengths

Lawrence J. Giacoletto/PhD/Dynatron Oscillator Operation with Particular Emphasis to a New Saw-Tooth Current Oscillator

Earle L. Kent/PhD/A Method of Changing the Frequency of a Complex Wave

Jules S. Needle/PhD/The Insertion Magnetron: A New External-Cavity Magnetron for Low-Power Electronically-Tunable Operation in the 10 to 20-CM Wavelength Range

Queenie H. Shirley/PhD/The Fusing of Ceramic Colors Unto Glass by Dielectric Heating

Ernest H. Wakefield/PhD/The Opening of the Proportional Region to Beta Counting and the Development of Two Flow Beta Counters

Homer W. Welch/PhD/Dynamic Frequency Characteristics of the Magnetron Space Charge: Frequency Pushing and Voltage Tuning

1953 Wilfred A. Bychinsky/PhD/Analytical and Experimental Investigation of Illumination from Interreflecting Surface Sources

Edwin E. Henry, Jr./PhD/The Thermistor as a Device for the Meas-

urement of Velocity in Flowing Water
Kaikhooshro B. Irani/PhD/A Method of Determining an Intrinsically Phase-Equalized Filter Transfer Function
Roger C. Quisenberry/PhD/An Analysis of System Recovery Voltages and Methods for Reducing Their Severity
Mrs. Rajeswari-Chattejee/PhD/The Eccles-Jordan Trigger with Special Attention to Transition Time
Charles B. Sharpe/PhD/Tchebycheff RC Filters
1954 Irving Bogner/PhD/An Investigation of the Switching Criteria for Higher Order Contactor Servomechanisms
Joseph A. Boyd/PhD/An External Cavity Voltage-Tunable Magnetron for the Frequency Range 1500 to 3000 Megacycles
William Kerr/PhD/A Beta-Ray Microscope
Paul R. McIsaac/PhD/A Study of the Initial Permeability of Ferromagnetic Metals at High Frequency
William W. Peterson/PhD/The Trajectron: An Experimental DC Magnetron
Thomas M. Stout/PhD/A Step-by-Step Method for the Transient Analysis of Nonlinear Feedback Systems
Thomas E. Talpey/PhD/A Study of Induced Grid Noise
1955 Hugh W. Batten/PhD/Plasma Fluctuations in Crossed Electric and Magnetic Fields
Edward Erdeyli/PhD/Predomination of the Sound Pressure Levels of Magnetic Noise in Medium Induction Motors
David Helman/PhD/Synthesis of Electric Filters and Delay Networks Using Tchebycheff Rational Functions
Branch P. Kerfott, Jr./PhD/Transistors in Analogue Computing
Richard E. Kuba/PhD/A Phase Space Method for the Synthesis of Nonlinear Servomechanisms
Joseph Otterman/PhD/Aperture Correction for Instrumentation Systems
Joseph E. Rowe/PhD/A Large-Signal Analysis of the Traveling Wave Amplifier
1956 Dale M. Grimes/PhD/Reversible Susceptibility in Ferromagnets
Phil H. Rogers/PhD/Large Signal Analysis of the Traveling Wave Amplifier
Ju Ching Tu/PhD/An Algebraic Approach to the Synthesis of Equalizers for a Prescribed Frequency Response
Charles R. Vail/PhD/An Investigation of Impulse Voltage Breakdown in Polyethylene
1957 Ben F. Barton/PhD/The Synthesis of Multi-Channel Amplifiers
Lynn A. Beattie/PhD/Minimum Energy Triggering Signals
Ralph D. Goodrich/EE/Simplified Analytical Solutions of Transmission System Problems
Doddaballapur Subrahmanyam/PhD/A Narrow Band Speech Transmission System
1958 Kuei Chuang/PhD/A Study of Nonlinear Systems with Random Inputs
Carl Doman/EE/The Electrical Engineer's Responsibility for the 1965 Motor Vehicle
George E. Dombrowski/PhD/A Small-Signal Theory of Electron-Wave Interaction in Crossed Electric and Magnetic Fields

1959 Robert L. Boggess/PhD/Bipolar Probe Measurements in the Ionosphere
Hansford W. Farris/PhD/Alternative Detection of Modulations in Co-Channel Frequency Modulation
Robert E. Frese/PhD/Study of the Use of Non-Simultaneous Measurements in Triangulation
Harvey L. Garner/PhD/Error Checking and the Structure of Binary Addition
Bernard Hershenov/PhD/A Small-Signal Field-Theory Analysis of Crossed-Field Amplifiers
William L. Kilmer/PhD/The Reliability Problem in Digital Computer Nets
Murray H. Miller/PhD/Study of High-Temperature (etc.)
Kenneth A. Stone/PhD/An Analysis of Fluid-Powered Control Systems and a Study of the Effects of Fluid Transmission Lines
Weston E. Vivian/PhD/Transport of Noise at Microwave Frequencies Through a Space-Charge Limited Diode

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1960 Mohammad A. El-Moslimany/PhD/Theoretical and Experimental Investigation of Radioactive Ionization Gauges
Arch W. Naylor/PhD/A Study of Forced Oscillations in a Class of Nth-Order Nonlinear Feedback Systems
Henry Ruston/PhD/Synthesis of RLC Networks by Discrete Tschebyscheff Approximation of the Time Domain
Harold Sobol/PhD/Modulation Characteristics of O-type Electron-Steam Devices

1961 George D. Breen/EE/Development of a Digitalized Voltage Generator for Ionospheric Probe Measurements
Pieter G. Cath/PhD/The Synthesis of Nonuniform Transmission Lines
Richard T. Denton/PhD/Longitudinal Pumping on Ferromagnetic Materials with Application to a New Type of Microwave Parametric Amplifier
Om P. Gandhi/PhD/Nonlinear Electron-Wave Interaction in Crossed Electric and Magnetic Fields
Robert O. Harger/PhD/The Optimization of Some Noisy Nonlinear Systems
George A. Hellwart/PhD/Speech Signal Analysis Utilization: Continuously Tuned Automatic Tracking Filters
Yen S. Lim/PhD/A Study of Forced Oscillation Systems with Nonlinear Restoring and Nonlinear Damping Forces
David B. Miller/PhD/Acceleration of Plasmas by Inductively Generated Electromagnetic Fields
Walter M. Nunn/PhD/A Small-Signal Analysis of E-Type Traveling-Wave Devices
Marti A. Plonus/PhD/A Study of the Biconical Antenna
William A. Porter/PhD/A Generalized Statistically Optimum Velocity Inertial System
Marlin P. Ristenbatt/PhD/Investigation of Narrowband Waveforms Generated by Clocked Pulses
Donald P. Rozenberg/PhD/An Investigation of the Algebraic Properties of the Residue Number System

1962 Thomas W. Butler/PhD/Precise Frequency Synthesis Using Non-Precise Tuning Components

Robert B. Crane/PhD/On the Use of Complex Filters

Martin Golinsky/PhD/An Analytical Determination of the Existence of Optimum Points in a Class of Networks

John G. Meeker/PhD/Phase Focusing in Linear-Beam Devices

Dale C. Ray/PhD/The Low-Temperature Order-Disorder Transition in Natural Magnetite and Synthetic with Varying Degrees of Doping

Surenda N. Samaddar/PhD/Wave Propagation in an Anisotropic Column with Ring Source Excitation

1963 David K. Adams/PhD/A Study of Double-Sideband Reactive Mixers

Abd E. M. Y. Bilal/PhD/The Analysis of a Certain Class of Non-linear Systems

George I. Haddad/PhD/Efficiency and Start-Oscillation Conditions in Nonuniform Backward-Wave Oscillators

Harrett Hazeltine/PhD/Three Problems in the Synthesis of Switching Circuits

Harvey W. Krage, Jr./EE/Noise Characteristics of High-Power Microwave Amplifiers

Andrew F. Nagy/PhD/Theoretical Investigation of Sounding Rocket and Satellite Borne Ion Traps

Carmen J. Palermo/PhD/Theory of Stochastic Delays

William J. Parker/EE/Equivalent Circuits as Applied to Automotive Intake Silencers

Anthony J. Pennington/PhD/Conditions on Structure Matrices of N-Port, Immitance-Equivalent Electric Network

Thomas F. Piatkowski/PhD/N-Head Finite State Machines

Leonard J. Porcello/PhD/An Experimental Study of Rapid Phase Fluctuations Induced Along a Satellite-to-Earth Propagation Path

Alphonse A. Toppeto/PhD/Switching Model for Finite Length, Thin-Film, Cylindrical Shell

Vincent A. Vis/PhD/Photoconductivity and Noise in Tellurium

Cheng Wen/PhD/Noise in Multi-Dimensional Electron Streams

1964 Arlon T. Adams/PhD/The Rectangular Cavity Slot Antenna with Homogeneous Isotropic Loading

Fredric Nelson Bailey/PhD/Stability in Interconnected Systems

Michael L. Burrows/PhD/A Theory of Eddy-Current Flow Detection

Dario Castellanos/PhD/On a Class of Integral Equations and its Applications to the Theory of Linear Antennas

Herbert Hacker, Jr./PhD/Low Temperature Magnetic Susceptibilities of Six Rare Earth Oxides

Elmer L. Johansen/PhD/Some Applications of the Wiener-Hopf Technique in Guided Wave Problems

Marshall C. Y. Kuo/PhD/The Application of Functional Analysis to Solve a Class of Linear Control Problems

Vernon L. Larrowe/PhD/Analog Computer Measurements of Time-Varying Power Spectra

William N. Lawrence/PhD/A Study of Radiation Controlled Arc Discharge Wind Tunnels

Mao-Shiu Lin/PhD/A Study of the Antiferromagnetic Transitions of Three Ionic Compounds at Low Temperatures

Nino A. Masnari/PhD/Analysis of Crossed-Field Space-Charge Flows
Joseph Merdler/EE/Stability of Solutions of Second-Order Ordinary Differential Equations
Joseph C. Palais/PhD/Impedance and Radiation Characteristics of a Ferrite Obstacle in the Aperture of a Rectangular Waveguide
Demetrios T. Politis/PhD/Analysis of Randomly Varying Propagation Circuits
Thammavarapu R. N. Rao/PhD/The General Properties of Finite, Weighted Number Systems
Klaus L. Volkholz/PhD/Energy Exchange in Crossed-Field Systems
Rajindar P. Wadhwa/PhD/Noise Transport in Crossed-Field Devices
Tiong S. Yu/PhD/Ferroelectric Tape Recording and Reproducing Processes

1965 Bruce W. Arden/PhD/On the Cubical Covering Problem
Shu-Yun Chan/PhD/Analysis of Variations in Optimal Control Systems Subject to Deterministic and Stochastic Disturbances
Mohamed E. A. El-Shandwily/PhD/Analysis of Multi-Signal Traveling Wave Amplifier Operation
Clarence C. Ferris/PhD/A Study of RADA (Random Access Discrete Address) Communications Systems
Dennis Fife/PhD/The Optimal Control of Queues, with Application to Computer Systems
Caxton C. Foster/PhD/Parallel Execution of Iterative Algorithms
William C. Grimmell/PhD/The Existence and Characteristics of Solutions to a Class of Linear Optimal Control Problems
Edmund K. Miller/PhD/The Excitation of Surface Currents on a Plasma Immersed Cylinder by Incident Electromagnetic and Electrokinetic Waves
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Richard A. Roberts/PhD/Theory of Signal Detectability: Composite Deferred Decision Theory
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Frederick M. Waltz/PhD/Minimum Peak Amplitude Control
Wei-ming Wang/PhD/Acoustical Analysis of Symmetrical Multi-Source Mechanically Driven Fluid Systems
Yung-Kuang Wu/PhD/Unified Approach to Excitation Problems in Compressible Plasma

1966 James A. Bennett/PhD/A Direct Determination of Turboalternator Dynamic Stability Limits
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Thomas A. DeMassa/PhD/Nonlinear Interaction Theory for Crossed-Field Distributed Emission Amplifiers
Chi Fu Den/PhD/Admittance of a Wedge Excited Co-Axial Antenna with a Plasma Sheath
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Robert Fischl/PhD/On the Best Chebyshev Approximation of an

Impulse Response Function at a Finite Set of Equally Spaced Points
Rodulfo Gonzalez/PhD/Synthesis Problems in Linear Threshold Logic
Kenneth A. Haines/PhD/The Analysis and Application of Hologram Interferometry
Richard L. Haken/EE/The Logical and Circuit Design of a Magnetic Coil Memory System
Dwight Stuart Heim/PhD/The Synthesis of Nonuniform Transmission Lines
John E. Herman/PhD/Hydrostatic Pressure Effects on the EPR Spectra of Doped Sapphires
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Ronal Worthington Larson/PhD/A Study of the Inhomogeneously Sheathed Spherical Dipole Antenna in a Compressible Plasma
Shreedhar G. Lele/PhD/Noise Characteristics of Convergent Crossed-Field Space-Charge Flows
Valdis V. Liepa/PhD/Theoretical and Experimental Study of the Scattering Behavior of a Circumferentially Loaded Sphere
Sudhindranath Pyati/PhD/A Study of Absolute Stability in Nonlinear Control Systems
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James H. Herzog/PhD/Proprioceptive Cues and Their Influence on Operator Performance in Mutual Control
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James E. King/PhD/Nonisothermal Wave Propagation and Instabilities in Bulk Semiconductors
Robert J. Martin/PhD/Experimental Investigation of the Low- Volt-

age Arc in Noble Gases

Donald G. Mueller/PhD/Optimal Space-Time Signal Processing and Parameter Estimation with Emphasis on Its Application to Direction Finding

David E. Oliver/PhD/Impedance Characteristics of Pumped Varactors

George G. Rassweiler/PhD/Helical and Log Conical Helical Antennas Loaded with an Isotropic Material

Robert C. Restrick III/PhD/Electromagnetic Scattering by Moving Bodies

Sang Bin Rhee/PhD/Monopole Antenna with a Finite Ground Plane in the Presence of an Infinite Ground

Sheldon N. Salinger/PhD/Simulation and Analysis of the Low-Voltage Arc Mode in Plasma Diodes

John L. Smith/PhD/Markov Decisions on Partitioned State Space, and the Control of Multiprogramming

Ronald L. Spooner/PhD/Theory of Signal Detectability: Extension to the Double Composite Hypothesis Situation

Ferrel G. Stremler/PhD/Estimation of Phase Differences Between Stochastic Narrowband Signals

Robert J. Urquhart/PhD/Degree Constrained Subgraphs of Linear Graphs

Rodger M. Walser/PhD/A Study of Thin Film Magnetodielectrics

Lee J. White/PhD/A Parametric Study of Matchings and Coverings in Weighted Graphs

Pei-Rin Wu/PhD/A Study of an Interdigital Array Antenna

Fred Zwas/PhD/Wave Propagation in Inhomogeneous Media

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Nicholas G. Alexopoulos/PhD/Electromagnetic Scattering from Certain Radially Inhomogeneous Dielectrics

John Asvestas/PhD/Iterative Solutions of Maxwell's Equations

Roger Badertscher/PhD/Electrical Conduction in Discontinuous Metal Films

Pierre Bauer/PhD/The Cooling of the Protonosphere

William D. Becher/PhD/Vertical Geoelectric Exploration Utilizing Nonuniform Transmission Line Theory

Jack E. Boers/PhD/Computer Simulation of Space-Charge Flows

Charles A. Brackett/PhD/Harmonic Current Generation and Multi-Signal Effects in Beam-Plasma Systems

Arthur R. Braun/PhD/Network Function Determination from Partial Specifications

Chao-Chun Chen/PhD/An Analysis of the Behavior of the HE_{11} Mode Ferrite Tube Antenna

Jerome A. Colligan/PhD/Mathematical Modeling and Parameter Identification for a Tracking System

Harry Detweiler/PhD/Characteristics of Magnetically Focused Large-Signal Traveling-Wave Amplifiers

William J. Evans/PhD/Nonlinear and Frequency Conversion Characteristics of Input Diodes

Ahmad Z. Faruqi/EE/Bandwidth Requirements of a Cylindrical Electrostatic Probe Experiment

Albert Friesem/PhD/Three Dimensional Recording Media in Holography

Charles C. Hoopes/PhD/Study of Pseudo-Random Number Generators

Christopher V. Kimball/PhD/Intersymbol Interference in Binary Communication Systems

David Levine/PhD/Wave Propagation Near the Coupling Point in Thin Slabs in Inhomogeneous Warm Plasma

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William Rado/PhD/Focused-Laser-Beam-Induced Frequency Shift in the Stimulated Raman Effect from Hydrogen Gas

Paul Tallerico/PhD/Relativistic Effects in the Traveling-Wave Amplifier

Vijai K. Tripathi/PhD/Varactor-Loaded Ladder Lines for Traveling-Wave Parametric Amplifiers Voltage-Tunable Microwave Circuits

Lambert R. Vander Kooi/PhD/Minimax Control of Continuous Time Stochastic Systems

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Seichoong Chang/PhD/Scattering by a Spherical Shell with a Circular Aperture

James L. Daws, Jr./PhD/Partial Period Correlation of Pseudo-Random Binary Sequences

Constantine Digenis/PhD/Antenna Sidelobe and Coupling Reduction by Means of Reactive Loading of the Group Plane

Dixon Doll/PhD/Efficient Allocation of Resources in Centralized Computer-Communication Network Design

Patrick N. Everett/PhD/Transitions of the $4T_2$ State in Pink Ruby and Development of Measuring Techniques for Short Lifetimes

Medhat Ibrahim/PhD/Coupling Analysis of a Loaded and Unloaded Pair of Rectangular Waveguide Cavities in an Infinitely Conducting Ground Plane

David Jaarsma/PhD/The Theory of Signal Detectability: Bayesian Philosophy, Classical Statistics, and the Composite Hypothesis

John E. Johnson/PhD/On the Controllability of Systems with Time Delays

Chaman Kashkari/PhD/Methods of Improving Transient Stability of a Synchronous Generator

Galal E. Khadr/PhD/Computer Approach to Economic Power System Scheduling

Deen D. Khandelwal/PhD/Characteristic of the Quenched-Domain Mode of Gunn-Effect Devices

Gerhard Konrad/PhD/Harmonic Generation in Nonlinear Beam-Plasma Systems

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Solaimanul Mahdi/PhD/Iterative Synthesis of Tem-Mode Distributed Networks

Hasso Niemann/PhD/An Atomic Oxygen Beam System for the Investigation of Mass Spectrometer Response in the Upper Atmosphere

William W. Parker/PhD/The Interdigital Array as a Boundary Value Problem

Mark K. Scherba/PhD/Characteristics of Noise Modulated High-Power Microwave Amplifiers

Theodore Seling/PhD/An Upper Limit to the Abundance of He^3II in Messier 17

Jon A. Soper/PhD/The Scattering of Electromagnetic Waves by Moving Bodies

Richard Talsky/EE/High Frequency Transistor Incremental Measurements and Models

Herbert C. Towle, Jr./PhD/Design Criteria for Nonlinear Feedback Systems

Victor Wallace/PhD/The Solution of Quasi Birth and Death Processes Arising from Multiple Access Computer Systems

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Alan G. Cha/PhD/A Bifilar Helical Antenna with an Outer Layer of Ferrite

Richard H. Hu/PhD/Anomalous Diffusion Effect in a Cylindrical Plasma Column

George R. Mattson/PhD/Electromagnetic Plane Wave Scattering by a Perfectly Conducting Disk

Chong K. Rhee/PhD/Ultrahigh Vacuum Studies on the Electrical Properties of Germanium Thin Film

LIKE ALL HUMAN TRIBES, ENGINEERS HAVE THEIR MYTHS AND LEGENDS, THEIR HEROES AND HISTORY, THEIR SOCIAL RULES AND THEIR POLITICAL STRUCTURE. TO IGNORE THIS FACT OF TRIBAL, CULTURAL LIFE IS TO IGNORE NOT ONLY HALF THE INTEREST BUT HALF THE ART OF ENGINEERING.

A. D. MOORE