MARION LEE EDWARDS

THE MASTER'S DEGREE PROGRAM IN ELECTRICAL ENGINEERING

The Master of Science in Electrical Engineering was the first degree to be offered through the Applied Physics Laboratory in what was then the Evening College of The Johns Hopkins University (McCoy College). Today it is the fastest growing master's program in the Continuing Professional Programs, having doubled in size over the last five years. The program is described, including its history, organization, and areas of concentration.

INTRODUCTION

The Massachusetts Institute of Technology Centennial Study Committee, chaired by Robert M. Fano, the distinguished professor and Chairman of MIT's Department of Electrical Engineering and Computer Science, concluded that "The future vitality and competitiveness of U.S. high-technology industry depend on widespread acceptance of lifelong formal educational activities as integral components of productive engineering work."[1]

Certainly the electrical engineering field has abundant evidence to support the committee's conclusion. No other profession has witnessed such transformation over the last 25 years; the routine personal calculating tools of the engineer have changed from the slide rule to the hand calculator and then to the computer. The technology has progressed from individual transistors to integrated circuits consisting of a hundred thousand devices. Optical devices and media, superconductivity, microwave and high-speed circuits, neural networks, and multidimensional and image processing are evidence of the exciting innovations that have occurred in electrical engineering.

The MIT report continues:

> The present rapid rate of scientific and technical innovation invalidates one of the basic assumptions underlying the traditional structure of engineering education: that a few years of formal education can provide an adequate foundation for a lifetime of professional engineering work. The demand for highly creative, up-to-date engineers has intensified during the last decade as a result of the rapid growth of the knowledge-intensive industry and of the increasing competition for national and international markets . . . Thus, engineers are faced with the problem of learning, during their professional lives, what new generations of engineering students are currently learning in school. Otherwise they risk becoming professionally obsolete at an early age, or prisoners of specialties that no longer provide rewarding career opportunities.[1]

Fano's committee concluded the following: lifelong education requires the cooperation of local industry and the university; schools should offer a master's degree for working engineers; schools should seek the help of industrial experts in specialized courses, thereby extending their scope of course offerings; and academic departments should support and encourage standards that permit students to take courses from either the full- or part-time curriculum.

This description of needs and the proposed solution are very familiar to The Johns Hopkins University. The Applied Physics Laboratory early recognized the value of these concepts and has been in an ideal position to promote on-the-job formal education. In addition to the obvious benefits and satisfaction in extending an individual's technical strengths, such a program offers satisfaction to part-time instructors who are full-time engineers. Teaching provides an opportunity to organize and structure new technical material in an area of interest, an opportunity not always available in the normal work environment. JHU's Master of Science in Electrical Engineering (MSEE) Program attracts many instructors who are motivated by this opportunity, and that is probably the most important reason for the high quality of the program. New fields of concentration in electrical engineering, such as computer engineering, microwaves, and optical engineering, have emerged because of the desire of working engineers to assimilate, organize, and communicate knowledge in those areas.

PROGRAM HISTORY

The program leading to a master of science degree in electrical engineering has been the fastest growing of the Continuing Professional Programs over the last five years. During that period the number of degree candidates has more than doubled, from 288 in 1984 to 609 in 1988, as shown in Fig. 1, and the number of electrical engineering degree candidates has increased from 20% to 35% of all the master's degree candidates in the Continuing Professional Programs.

Today, electrical engineering students represent slightly over one-third of the total student body, and the number of electrical engineering classes has tripled. The MSEE Program continues to serve participants from APL, with about 11 students graduating each year between 1984 and 1988; growth is due to participation of students from other organizations, where the number graduating has risen from 40 to 115. Fortunately, an in-

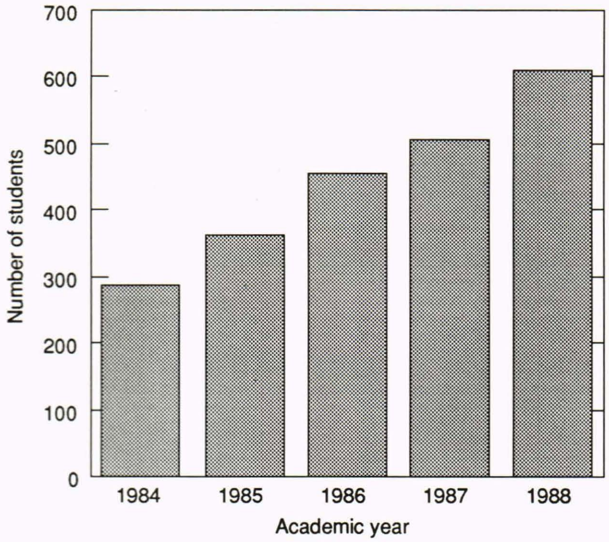

Figure 1—The number of MSEE degree candidates between 1984 and 1988.

crease in qualified faculty has accompanied this growth, reducing the average class size from 31 to 22 students over the last five years.

The MSEE degree was the first to be offered through APL in what was then the Evening College of The Johns Hopkins University (McCoy College). It was the only master's degree announced in the first catalog, issued for the 1964-65 academic year. The program was and still is aimed at providing graduate education for academically strong persons who have previously obtained a bachelor of science degree in electrical engineering. Candidates demonstrating outstanding ability in related technical areas also are encouraged to apply; they may become MSEE degree candidates after approval by a special admissions committee and the completion of background courses if necessary.

When the program began, requirements were two semesters of mathematics, two semesters of physics, six semesters of electrical engineering courses, a reading knowledge of French, German, or Russian, and the completion of a master's essay. The six electrical engineering courses had to be taken from two of three areas of concentration: materials, systems, and signals. Three years later, in the 1967-68 academic year, the language and essay requirements were dropped, but 12 courses were then required for graduation.

In 1983, the program was transferred, with the other APL-based programs, to the newly created G. W. C. Whiting School of Engineering; specifically, it was integrated into the Part-Time Engineering Program, whose first director was Theodore Poehler. Under Poehler's direction, committees were established to oversee and promote the various programs. The Director (and others) also felt that students should have assistance in planning their courses, and he therefore set up a system of advisors, a core of established instructors willing to help students new to the system or students having academic or administrative problems.

Vincent Pisacane was appointed the first Chairman of the Electrical Engineering Program Committee, made up of several faculty members from APL and two from the Electrical Engineering Department at JHU's Homewood Campus. Under Pisacane's direction, the program was restructured. Existing courses were evaluated and new courses proposed. To allow students to specialize more if they desired, the program was divided into five areas of concentration: Communications and Radar Systems; Signal Processing; Computer Engineering; Electronics and Solid State; and Systems, Networks, and Control. Two more areas, Microwave Engineering and Optical Engineering, were later added. The number of courses required for graduation was changed to ten, the number required today. Many of the original courses have since been dropped and new ones added. An overview of the course development is presented in Tables 1 through 7.

An admissions subcommittee was formed to evaluate applicants who did not formally meet minimum requirements (a bachelor of science degree in electrical engineering from an accredited school, a 3.0 or better grade point average for all technical courses, and a 3.0 or better grade point average for the last half of the student's undergraduate program). The subcommittee is particularly sensitive to applicants from other fields who may seek a master's degree in electrical engineering and it considers all available information, including academic potential, technical course experience, and work ex-

Table 1—Communications and Radar Systems course history.

	Academic Years Offered
Information and Signal Processing I and II	1965–72
Principles of Radar I and II	1968–89
Coding Theory I and II	1971
Statistical Decision and Communication Theory I and II	1971–72
Communications Systems Engineering	1972–81, 1983–89
Digital Communications Theory I and II	1973–76
Error Control Coding	1980, 1982–89
Advanced Topics in Communications Systems	1981–87
Digital Switching and Telephony	1985–89
Propagation of Radio Waves in the Atmosphere	1985–89
Information Theory	1986–89
Fundamental Concepts in Communications I and II	1988–89
Special Topics in Communications	1988–89
Satellite Communications Systems	1989

Table 2—Microwave Engineering course history.

	Academic Years Offered
Antenna Systems	1979-89
Electromagnetic Transmission Systems	1981-89
Principles of Microwave Circuits	1985-89
Mathematical Methods	1985-89
Microwave Circuit Analysis I and II	1986-89
Electromagnetics	1986-89
Microwave Circuits Laboratory	1987-89
Microwave Engineering Laboratory	1987-89
Microwave Monolithic Integrated Circuits Design	1989
Microwave Subsystem Design	1989

Table 3—Computer Engineering course history.

	Academic Years Offered
Advanced Digital Techniques I and II	1967-72
Theory of Digital Systems I and II	1983-89
Computer Architecture	1984-89
Microprocessor Systems	1984-89
CAD of Digital Systems	1985-89
Computer Communications Networks	1985-89
Parallel Processing Systems	1985-89
Digital Design for Test and Fault Tolerance	1986-89

Table 4—Electronics and Solid State course history.

	Academic Years Offered
Solid State Fundamentals I	1965
Solid State Fundamentals II	1965-1966
Microelectronics	1979, 1981
Physics of Semiconductor Lasers	1982
VLSI Technology and Applications I and II	1982-89
Introduction to Electronics and Solid State I and II	1984-89
Advanced Electronic Design	1988-89
Introduction to Electronic Packaging	1989

Table 5—Signal Processing course history.

	Academic Years Offered
Introduction to Differential Games	1973
Digital Filters	1973-89
Analysis of Random Data	1974-80
Detection and Estimation Theory	1977-89
Introduction to Pattern Recognition	1977-89
Digital Signal Processing	1983-89
Random Signal Processing and Time Series Analysis	1984-89
Image Processing	1984-89
Speech Processing	1985-89
Optimal Estimation Theory	1985-89
VLSI Signal Processing	1986-89
Digital Signal Processing Laboratory	1987-89
Advanced Topics in Signal Processing	1987-89
Multidimensional Digital Signal Processing	1987-89
Modern Analog Signal Processing	1988-89
Adaptive Signal Processing	1989
Analysis of VLSI and Neural Networks I and II	1989
Time Series Analysis	1989

Table 6—Systems, Networks, and Control course history.

	Academic Years Offered
Network Synthesis I and II	1964-72
Continuous Control Systems I	1966-89
Continuous Control Systems II	1966-83
Modern Systems and Control Theory I and II	1972
Kalman Filtering	1979-81
Digital Sampled Data Control	1981-89
Linear System Theory	1983-89
Nonlinear System Theory	1984-89
Optimal Control Theory	1985-89
Control System Design Methods	1987-89
Probability and Stochastic Processes	1988-89

perience. On the basis of these criteria, the admissions subcommittee issues the following rulings: admit applicant, admit applicant but with conditions, require applicant to take preadmission courses, or reject. Experience is often an important ingredient in a student's development. Some of the best students are those who performed marginally in undergraduate school and have worked for four or five years before entering the MSEE Program.

In 1984 Vincent Pisacane was appointed to head the Space Department at APL, and Robert N. McDonough became the new Program Chairman. When McDonough

Table 7—Optical Engineering course history.

	Academic Years Offered
Fiber Optic Systems	1983-84, 1989
Laser Electronics I	1985-89
Optical Signal Processing	1985-89
Laser Electronics II	1988-89
Waves and Fields in Optoelectronics	1985-89
Optical Propagation	1988-89
Fourier Optics	1989
Statistical Optics	1989

received a one-year visiting professorship appointment at the Homewood Campus in 1986, I succeeded him as Chairman. Because of the growth of the MSEE Program, the position of Vice-Chairman was created and McDonough assumed it upon his return. Also, course area coordinators were identified to foster the continued development of the various areas and to assist in the recruitment and selection of new faculty members.

THE MSEE CURRICULUM

Sixty-seven courses in seven areas make up the current curriculum for the MSEE Program. Students are encouraged to focus on one or two areas (see Tables 1-7, which include all courses given since the inception of the program).

Communications and Radar Systems encompasses a comprehensive selection of systems-level courses in fundamental and advanced concepts of the transmission and detection of information.

Microwave Engineering focuses on modern design and analysis of solid-state circuits, including the use of modern computer-aided design (CAD) techniques to evaluate realistic designs. Students are exposed to practical considerations of design, fabrication, and testing in introductory and advanced laboratory courses. The Microwave Laboratory has modern test equipment, including a Wiltron 360 Network Analyzer, which can make precise measurements in a frequency range up to 40 GHz (Fig. 2). Interest in this area is reflected in Fig. 3. A monolithic microwave integrated circuit course, in which student designs are fabricated and tested, will be offered for the first time in the summer of 1989 (see Fig. 4).

Computer Engineering concentrates on the design of special-purpose computing systems, rather than general-purpose computers. The curriculum stresses hardware considerations and software concepts essential to the implementation of modern technology in digital applications. A hands-on approach is emphasized through the use of student suitcase kits, which allow application exercises using microprocessors: sophisticated digital designs are executed with advanced CAD and simulation tools (see Fig. 5).

Electronics and Solid State addresses the design, analysis, and packaging of electronic equipment. Modern solid-state principles are emphasized, leading to integrated circuits and optoelectronic concepts. Again, CAD and simulations are used, and very large scale integration (VLSI) design projects are fabricated and tested (Fig. 6).

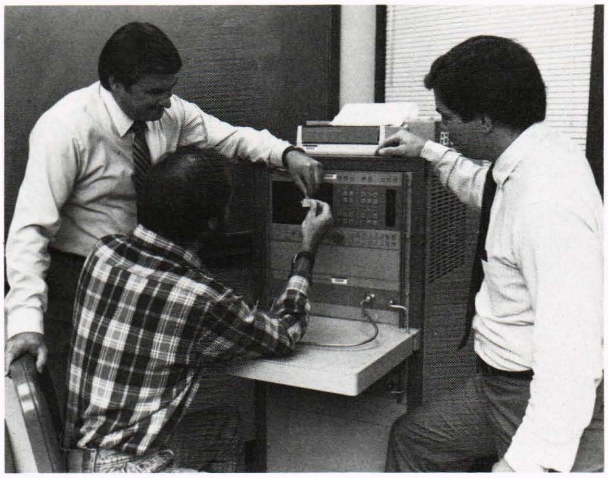

Figure 2—A student making a measurement on the Wiltron 360 Network Analyzer under the direction of Microwave Laboratory instructor Joseph Abita (left) and laboratory assistant Rich Huebschman (right).

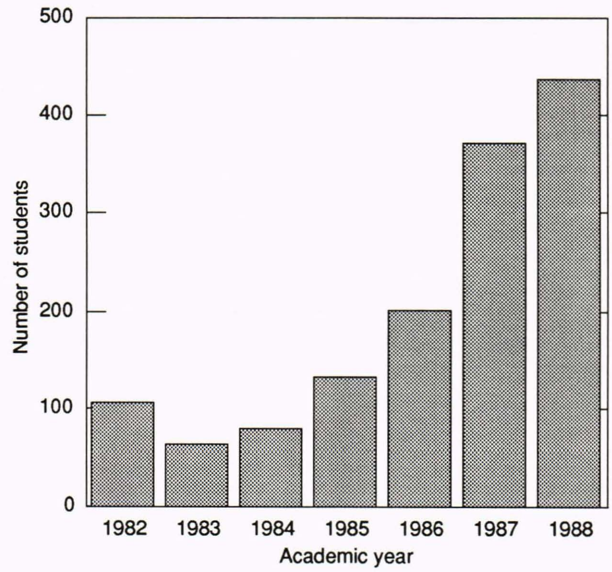

Figure 3—Microwave Engineering student registration from 1982 to 1988.

Signal Processing involves the handling and interpretation of data. The curriculum includes a broad selection of courses dealing with fundamental concepts, algorithmic techniques, and their applications to digital and analog representations of data signals associated with measurements, speech, or images.

Systems, Networks, and Control is a traditional area of electrical engineering from which many other areas developed. It focuses on the mathematical synthesis and analysis of electrical units intended to generate controlling responses based on input data and desired perfor-

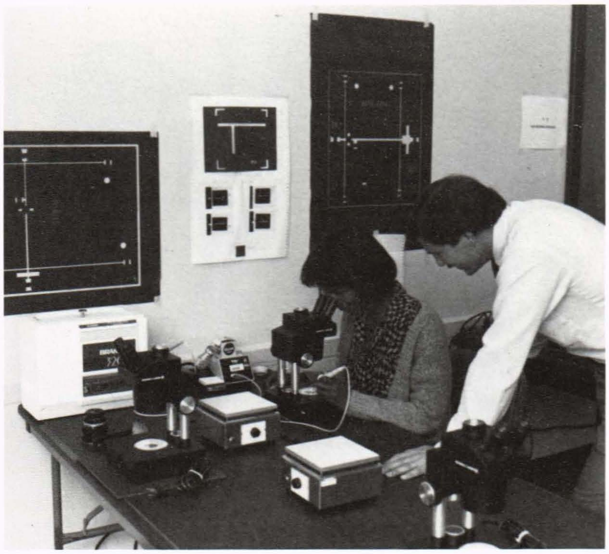

Figure 4—Instructional laboratory courses are part of the Microwave Engineering curriculum. Microwave integrated circuits will be fabricated in APL facilities such as those shown here.

mance. This area includes both linear and nonlinear as well as analog and digital systems. Design methods and optimal control theory are taught in advanced courses.

Optical Engineering is rapidly becoming an important field of study; courses focus on special propagation in materials and in the atmosphere. Optical sources and optical sensors are considered, permitting a student to gain valuable knowledge of systems applications.

The MSEE curriculum is committed to offering students a graduate education with hands-on experience and a realistic problem-solving environment. Laboratories have been developed, CAD features acquired, simulations created, and student kits assembled. Special projects also can be undertaken by students, under the supervision of a faculty member, to allow exploration in more depth or in new areas.

PLANNING A COURSE OF STUDY

Once accepted into the MSEE Program, a student is assigned an advisor and given a program plan form to complete. With the help and approval of the advisor, the student develops a plan identifying ten courses toward a master of science degree in electrical engineering. At least eight of the courses must be from the electrical engineering curriculum. Students can take two technical electives from courses offered in other Continuing Professional Programs or in the full-time graduate engineering departments, and are expected to take at least four upper-level courses as part of their program.

Within these constraints, advisors have broad discretion to approve a set of courses tailored to the students' individual goals. Students generally take courses from one, and sometimes two, concentration areas. The student can revise the plan as the graduate program advances by consulting with his advisor and obtaining the advisor's approval. The plan also allows the student to view his master's degree education in total and it encourages the selection of a coherent set of courses that will result in more depth and greater skill development.

The program plan system is being computerized so that the plans reside in a database accessible to the student and the advisor. Students can make their entries (and revisions) via terminals at any of the campuses, or remotely by using a personal computer and modem with public-domain communications software. As a student advances, the plan is updated to reflect performance, thereby enabling an advisor to recognize problems more quickly. Additionally, the scheduling information in the plan allows better forecasting of course demands and earlier recognition of the need for multiple sections of a course. Registration priority can be determined by this system, because plan inception and revision dates are preserved in the database.

Figure 5—A microprocessor class taught by Edwin Mengel (top) uses student suitcase kits (bottom) and a personal computer laboratory, providing hands-on experience to reinforce student learning.

Figure 6—Apollo and Compaq 386 work stations permit students to analyze and design digital and analog circuits in a state-of-the-art industrial environment.

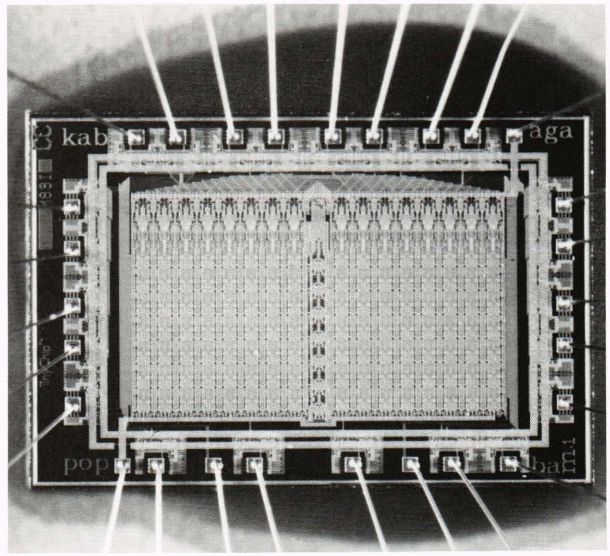

Figure 7—The bidirectional associative memory chip, based on a neural network architecture and designed by students Kwabena Boahen and Philippe Pouliquen, is an example of the collaborative effort between the MSEE Program and the ECE Department at Homewood.

THE STUDENTS

Most students in the MSEE Program are full-time employees in industry and government in the Baltimore–Washington area and live in Maryland, Northern Virginia, and Washington, D.C.; some live as far away as Pennsylvania and the Eastern Shore of Maryland. They are mainly recent graduates working at their first jobs who seek a graduate education while their undergraduate background is fresh. Others whose undergraduate degrees are less current wish to learn recent techniques appropriate for today's engineering environment. Still others in related scientific or mathematical professions may take background courses in electrical engineering to gain acceptance to the program and then continue with advanced education as a basis for a career change or to learn material germane to their current needs. Some participants enroll in the program as special students who are not interested in pursuing a degree but wish to take certain courses; they must, however, meet the same admission requirements as the degree candidates.

In every respect the student body is special. Almost all participate while meeting full-time responsibilities of families and employers. They are a mature and highly motivated collection of talented people. Many take courses after graduation, and some use their master's work as a foundation for obtaining a doctoral degree at Johns Hopkins or another university.

THE FACULTY

The faculty are mainly practicing electrical engineers from industry or government with an interest in imparting their knowledge to others. Of 54 faculty members, 76% have a Ph.D., and most of the others hold a master's degree. Three instructors are also full-time faculty members in the Electrical and Computer Engineering (ECE) Department at the Homewood Campus, and 63% of the faculty are full-time employees of APL.

Close collaboration exists between the MSEE Program and the ECE Department (see Fig. 7). Through Fitzgerald–Dunning Professorship appointments at the Homewood Campus, Robert Jenkins and I contributed, respectively, to the development of VLSI courses and the microwave curriculum in the ECE Department. Also, program faculty such as Quentin Dolechek, Andrew Goldfinger, and Robert Jenkins teach ECE courses in addition to their regular evening courses. Two courses are taught jointly by faculty from the MSEE Program and the ECE Department using the Instructional Television (ITV) that links Homewood and APL via microwave link.

The MSEE Program is administered by the Electrical Engineering Program Committee, which develops policy, oversees operations, encourages curriculum development, and recruits new faculty. The current committee members and their course area responsibilities are

Marion Lee Edwards, APL Chairman	Microwave Engineering
Robert N. McDonough, APL Vice-Chairman	Signal Processing
Bradley G. Boone, APL	Optical Engineering
Richard Gorozdos, APL	Systems, Networks, and Control
Robert Jenkins, APL	Computer Engineering
Richard I. Joseph, ECE	At-large
Pierre Lafrance, APL	Communications
Vincent Pisacane, APL	At-large
Charles R. Westgate, ECE Chairman, ECE Department	Electronics and Solid State

CAMPUSES AND FACILITIES

Electrical engineering courses are taught at three Johns Hopkins campuses: Homewood in Baltimore, the APL Center near Columbia, Maryland, and the Montgomery County Center in Shady Grove, Maryland. The Parkway Center near the Baltimore–Washington International Airport also houses multiple sections of electrical engineering courses. A microwave link permits classroom interaction between Homewood and APL via ITV facilities at each end (Fig. 8). The ITV systems allow real-time two-way video and audio communications between sites and high-speed access from one campus to high-performance or specialized computers at the other. The ITV classrooms have multiple cameras, special visual aid equipment, and student monitors to facilitate communications. An instructor can be at one campus and teach a class at the other, or simultaneously teach students at both locations with the ITV; two instructors, one at each location, can interact with both groups of students, thereby offering stimulating team teaching. Teaching aids include real-time computer simulation and display, combined with class videotaping for out-of-class viewing.

The MSEE Program uses several types of computer-aided engineering stations to support both analog and digital courses. Students learn to use computers to support their analyses and design efforts in an industry-relevant environment. Thanks to numerous donations, courses use state-of-the-art simulation and layout programs, such as Libra, Touchstone, and Academy, and customized instructor software.

Computer graphics and microprocessor courses use hardware specially configured to aid instruction. Students are given suitcase kits that allow experimentation with microprocessor hardware out of class. In-class testing and advanced instruction are performed in a classroom configured with personal computers designed to work with the kits. The classroom has an instructor station linked electronically to each student station, permitting the student to simulate and test the instructor's actions.

Courses in all areas of concentration use computer-aided instruction in various forms. Although computers should never replace the creative thinking involved in analysis and design, they can remove tremendous mechanical burdens, thereby allowing enhanced innovation.

Over the last several years, the MSEE Program has developed several instructional laboratories, such as the Microwave Laboratory (Fig. 2). An instructional sequence for that laboratory has been developed under the leadership of Joseph Abita. The first course, Principles of Microwave Circuits, teaches basic principles of microwave signals, measurement technique, and experimental investigation. The second, Microwave Engineering, focuses on the design of system components and modules, where engineering performance specifications must be satisfied and integrated electrically, mechanically, and thermally. The laboratory contains advanced equipment such as the Wiltron 360 Network Analyzer.

The program's hands-on philosophy of education is well illustrated in the VLSI courses. After becoming familiar with state-of-the-art design tools, students design chips suitable for fabrication by a foundry service. The analog VLSI is a result of close collaboration between Robert Jenkins in the MSEE Program and Andreas Andreou of the Homewood ECE Department. This technology uses field-effect transistors in their subthreshold state to generate computational elements, thereby permitting the design of application-specific VLSI chips with analog computing power. Test probe stations have been developed and student design projects undertaken. One of these projects, a bidirectional associative memory, designed by Kwabena Boahen and Philippe Pouliquen in a Homewood class (Fig. 7), has been fabricated in a prototype chip. The latest initiative is a digital signal-processing laboratory course. Students are given the opportunity to collect digital data from various sensors and to process signals in a real measurement environment. The course will include the processing of communication, radar, and optical sensor data provided to the class for processing and instructional use.

Figure 8—Students in the ITV facility are about to be linked to an off-site lecture. The ITV enables computer-aided engineering simulations to be conducted and displayed on individual monitors in real time.

CONCLUSION

The Johns Hopkins University Master of Science in Electrical Engineering Program is one of the largest in the country. It has doubled in size over the last five years. The program is broad-based, with seven areas of concentration. The student body is highly motivated and encouraged by advisors to structure a coherent program that meets individual goals. The faculty are a distinctive collection of academically qualified professionals who are also practicing engineers. An industry-relevant hands-on approach is used, including work stations, simulations, computer-aided engineering and design, and laboratories with circuit fabrication and test.

The current President of the Institute of Electrical and Electronics Engineers, Emerson W. Pugh, observed that "Of all the needs of electrical engineers, none is more important than maintaining technical currency . . .

What of the future? Are the big changes in electrotechnology behind us? . . . I think you know the answer as well as I . . . The rate of change in electrotechnology appears to be increasing rather than decreasing . . . The need for continuing education is clear."[2]

REFERENCES

[1] Massachusetts Institute of Technology Department of Electrical Engineering and Computer Science, Centennial Study Committee, *Lifelong Cooperative Education*, MIT Press, Cambridge, Mass. (2 Oct 1982).

[2] Pugh, E. W., "President's Column," *The Institute*, IEEE (Feb 1989).

THE AUTHORS

MARION LEE EDWARDS is branch engineer for the Space Electronics Systems Branch in APL's Space Department and is the program chairman of the Electrical Engineering Program in the G.W.C. Whiting School of Engineering. He is a leader in the development of microwave capability at The Johns Hopkins University and has developed several evening courses. As the J. H. Fitzgerald-Dunning Professor, he assisted in the development of the microwave laboratory program in the Electrical and Computer Engineering Department on the Homewood Campus. Dr. Edwards is an active participant in APL's Microwave Monolithic Integrated Circuit (MMIC) internal research and development and is a designer of the first APL custom-designed MMIC chip.