Distance Education for Microsystems Courses and Degrees

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Index Terms: Distance Education, Distance Learning, MEMS/Microsystems.

INTRODUCTION AND OVERVIEW

The Engineering Research Center for Wireless Integrated MicroSystems (WIMS ERC) has developed six microelectromechanical systems (MEMS) and Microsystems courses that provide a broad comprehensive curriculum for upper-level undergraduate students, graduate students, and industry professionals [1]-[4]. The curriculum was designed to provide students with a comprehensive background in MEMS/microsystems theory, fabrication, practice, applications, and technology. The courses accommodate students from broad academic disciplines across science and engineering, as well as industry professionals. Strong student enrollment exists in all the courses. These courses have led to the inclusion of MEMS/Microsystem topics in other courses, from sophomore-level to the advanced graduate level. The curriculum has been flexible enough to encourage creation of other courses, with links to broad interdisciplinary areas, such as electronic data converter circuits, solid-state theory and devices, nanotechnology, and materials.

Distance education was decided as the method to disseminate course materials (lecture notes, slides, homework, exams); this major decision was made even prior to development of the courses and materials. How could students at other universities and industry be served well using several distance education formats: real-time concurrent broadcasts, online with streaming video, recording and shipping DVDs, etc? The courses originate at the University of Michigan (UM) and have been disseminated to industry and universities worldwide:

<u>WIMS Core Partners</u>
Michigan State University (MSU)
Michigan Technological University (MTU)

<u>WIMS Collaborating Partners</u>
Howard University (HU)
Univ. of Puerto Rico – Mayaguez (UPRM)

<u>United States – Others</u>
Western Michigan University (WMU)
Rochester Institute of Technology (RIT)

<u>International</u>
University of Lille
Darmstadt University
Middle-East Technical Univ. (METU)

One course originates at MTU, and is disseminated to the WIMS core partners, MSU and UM.

With reliable distance education offerings of MEMS/Microsystems core and elective courses, a Master of Engineering (M.Eng.) degree in Integrated Microsystems, as well as a Certificate Program in Integrated Microsystems are available completely online; visit www.wimserc.org/education/education.php for other information. The requirements of the M.Eng. degree program include core courses (MEMS/Microsystems), technical electives (BioMEMS, RF MEMS, wireless communication, optical MEMS), breadth electives (manufacturing, management, etc), all online. An industry-oriented team project partners the student with a faculty member and a professional in industry in a project suggested by an industrial application. Part-time students can complete the M.Eng. degree in twenty months over the web. The requirements of the Certificate program include core MEMS/Microsystems/Electronics courses and technical/breadth electives.

Industry professionals are taking advantage of these course and degree offerings, with a steady increase in the number of participants. On-campus students take advantage of distance education resources during their review preparations for exams, as well as obtaining materials for unavoidable absences from class.

Thus courses, a degree program, and a certificate program are available via distance education. In this paper, methods for distance education dissemination via various formats are described. Also described are development of course materials and related resources for distance education, cost factors and comparison of the various distance education formats, as well as the responsibilities of local instructors at WIMS ERC partners. The WIMS Center and the UM distance education programs office provide assurances for course

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offerings so a student can make reasonable and continual progress to enroll in courses and toward degree or certificate completion.

WIMS Center Introduction and Structure

WIMS is a National Science Foundation (NSF) Engineering Research Center (ERC) with the University of Michigan – Ann Arbor (UM) acting as the lead university in partnership with Michigan State University (MSU) and Michigan Technological University (MTU). The ERC also involves research collaborations with faculty at five outreach universities: Prairie View A&M University, University of Puerto Rico – Mayaguez, North Carolina A&T State University, University of Utah, and Spelman College. WIMS has about 20 industrial partners, including Agilent, Freescale, Honeywell, Sandia, Schlumberger, Stryker, Textron, and Toyota. While NSF is the major funding source, each core partnering university contributes substantial cost-sharing. WIMS is composed of five research thrusts (Biomedical Sensors and Subsystems, Environmental Sensors and Subsystems, Wireless Interfaces, Micropower Circuits, and Advanced Materials, Packaging, and Processes), two cross-cutting microsystem testbeds (Implantable Neural Prostheses and a Wearable Environmental Monitor), an Industrial Liaison with responsibility to coordinate external outreach activities and industrial relations, and an Education Thrust with goals described in the next section.

Education Thrust Programs

The goals of the WIMS Education Thrust are to educate the next generations of engineers and scientists about WIMS and with WIMS, and to rapidly transfer results from the research domain to the classroom domain. Proactive diversity and outreach initiatives, as well as evaluation, are integrated within the programs. As depicted in Fig. 1, the Education Thrust provides comprehensive opportunities with three sub-components: pre-college programs for K-12 students, university programs for undergraduate and graduate students, and programs for practicing professionals and general society. For WIMS university education programs, the strategy is to provide courses, project and research opportunities, mentoring opportunities, access to industry relationships (such as internships and professional collegial relationships), and management/supervisory experiences.

Fig. 1. Comprehensive Scope of the WIMS Education Programs

MEMS/Microsystems Courses Introduction and Overview

The field of microelectromechanical systems (MEMS) and microsystems continues to grow and mature, necessitating more well-prepared professionals for industry, national laboratories, and research universities. Initially, universities offered individual courses [5][6], and now broad MEMS and microsystems curricula have evolved [1][4][7]–[10]. WIMS faculty have developed a set of five MEMS/microsystems core courses, as well as a set of augmenting and related BioMEMS and electronic circuit courses, as in Fig. 2 [11][1].

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The WIMS MEMS/microsystem curriculum was designed to accomplish several objectives [4][9]: (1) provide instruction in MEMS and microsystems theory, practice, applications, and technology, (2) accommodate students from broad disciplines across science and engineering by developing a first course that had minimal prerequisites in science (physics and chemistry), math, and engineering, (3) use the first course as the only prerequisite for the remaining core courses, (4) develop course materials with the expectation that distance education with web-based dissemination would be a primary format, (5) serve undergraduate and graduate students, as well as serve practicing professionals, (6) be available for students at all three partnering universities (UM, MSU, MTU), (7) develop skills in critical assessment of diverse technologies and devices, (8) develop engineering project management skills, (9) be a core set of requirements for a graduate professional degree program to accommodate practicing professionals desiring an advanced degree, and (10) be flexible enough to encourage creation of other courses with links to broad interdisciplinary areas.

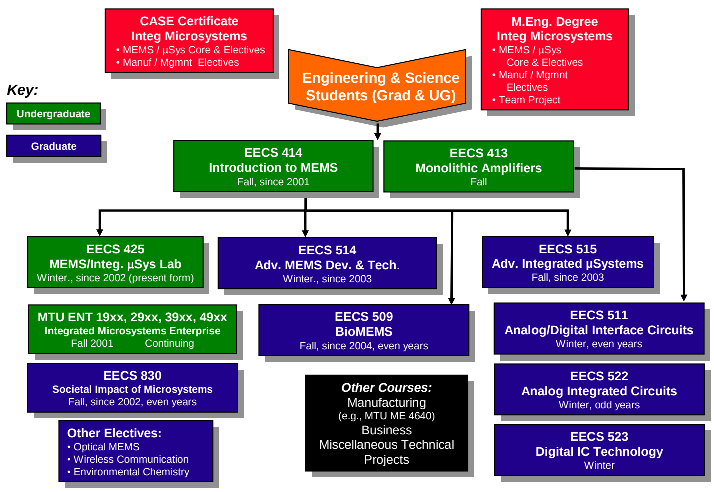

Fig. 2. MEMS/Microsystems Curriculum Design and Degree Programs

DISTANCE EDUCATION DISSEMINATION AND OTHER COURSES CONSIDERATIONS

Three distance education models are used to disseminate the MEMS and Microsystems assets (courses, degree and certificate programs). The lab course uses a fourth model that is described along with that course. The first model is referred to as the high-quality/high-cost studio model. The class meets in a classroom equipped as a broadcast studio with lighting, quality audio and video recording, and multiple cameras and microphones. High-quality video/audio of the recorded session is disseminated of the course materials, including the lecture and PowerPoint slides. The streaming video and course material are posted to the class web-site about one hour after the "live" class session. Initially, this approach was very high-cost; over the last year, the cost to the WIMS Center was reduced considerably and the cost approaches the lower-cost methods that are described next. In the early years of the decade, the cost per course approached $20,000 per course originated at UM. Now, the UM College of Engineering on-campus student tuition payments as part of the income from students, not just the tuition paid by distance education online students. Also, for this model, homework assignments originate at The University of Michigan and are posted online. Students turn in homework to their home university or email scanned copies of their solutions to the UM professor. Exams are emailed to the local proctor at each local site, for administration according to the course rules. Grading of homework and exams are done by the instructor at the local university; for purely online distance education students (such as industry professionals), homework solutions and student-worked exams papers are returned to The University of Michigan professor for grading.

The second model is to use the web-based system developed for courses at The University of Michigan, named CTools (for Course Tools). Each course has a CTools site available for use by the professor and students. All enrolled students and course staff have access to the course CTools site. Assignments, solutions, grade book, chat room, video, etc are all available at the CTools site. In this model, the class meets in a normal university classroom with typical digital projection equipment; video and audio are

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captured and recorded by a WIMS staff person operating a portable single camera; the streaming video of lectures and course materials are posted to a UM CTools web-site usually within a day after the “live” class session. Homework, exams, and other assignments and administration are exactly the same as for the first (high-quality/high-cost) model.

The third model is outright sharing of course materials. Some professors want to teach a version of the courses at their university; UM professors have been quite willing to provide source materials to requesting professors. Distance education dissemination of the courses is available in whole, or as sub-portions of course materials. The core courses have been distributed to WIMS core-partner and outreach universities, as well as internationally to several universities in Europe and the Middle East. Moreover, some universities have adopted large portions of the core courses, and made custom adaptations suitable for their universities; such sharing has been done with professors at Rochester Institute of Technology and Middle East Technical University.

During the discussions and design of the MEMS/microsystems core curriculum, it was decided that distance education dissemination would be the expected delivery mechanism for each core course. The core courses originate at UM. How could students at other universities and industry be served well? It was decided that local instructors would be available at other universities for several purposes: provide face-to-face office hours, grade homework, administer and grade exams, and assign grades to students at that university. Each university was encouraged to obtain course approvals with course numbers at their university, and to assign credit hours consistent for their university. University term calendars are different. The student pays tuition to his/her home university, and there is no inter-institutional financial sharing of tuition funds. Costs for online dissemination of courses are borne by the originating university.

The significance of this curriculum development initiative includes numerous factors. First is a coordinated set of comprehensive MEMS and Microsystems courses and educational resources that are readily shared internationally. The course materials are generously shared, either as a delivered course via distance education, or as a transfer of course materials to faculty who decide to teach the course locally at their university. Several renowned faculty contributed to development of the courses and course materials, making the materials worthy of international distribution. The next few sections identify courses separately with course content and distance education usage. Though this paper is segmented by courses, degree and certificate programs, distance education is the primary topic of this paper.

INTRODUCTION TO MEMS (EECS 414)

The first course was developed to be open to all engineering and science students with an interest in learning about MEMS, irrespective of their discipline. Course challenges and design considerations are described elsewhere [2]. Since micromachining technology affects all aspects of MEMS, the course starts with a detailed coverage of microfabrication and micromachining, including planar thin-film processes, photolithographic techniques, deposition and etching techniques, wafer bonding, and electroplating. These topics are followed by a detailed coverage of surface, bulk, and electroplating micromachining technologies and review of example devices. A designer of MEMS requires knowledge and expertise across several different disciplines. Therefore, this course pays special attention to teaching of fundamentals of transduction mechanisms (i.e. conversion of non-electronic signals to electronic signals), including capacitive, piezoresistive, and thermal techniques, and design and analysis of micromachined sensors and actuators. The course also introduces students to MEMS-specific computer-aided design (CAD) simulators, including Coventorware and ANSYS. Assignments allow students to use CAD tools to simulate a few sample structures and compare their operation to calculated values. Table 1 summarizes the topics covered in EECS 414 (highlighted in **bold blue font**) in the context of all topics that are covered in this MEMS and Microsystems core curriculum. The first course *Introduction to MEMS* (EECS 414) is the only prerequisite needed for follow-on courses.

After its first offering in Fall Term 2001, the reading materials resources have been course notes and PowerPoint slides that were developed by UM faculty, as well as numerous designated journal and conference articles [12]–[14]; these resources match the content and flow of the course. These resources have been readily shared and provided to others who seek to develop a course at their institution. The course has also been taken via the internet by students at several other institutions, and challenges in this area have been identified.

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Table 1. MEMS/Microsystems Topics for Three Courses

Materials/Fabrication	**Transducers**	**Microsystems**
Materials	Energy Domains	*Circuits*
Silicon & Related	**Electrical**	*Sensor & Actuator*
Semiconductors	**Mechanical**	*A-D Conversion*
Non-Silicon	**Thermal**	
Micro-Fabrication	Chemical/Gas/Bio	*System*
Photolithography	Optical/Radiative	*Architecture,*
Planar		*Partitioning*
Microfabrication		*Signal Processing*
Micromachining	Transduction Techniques	*Power Issues*
Photolithographic	**Capacitive**	*Power/Energy*
(Parallel)	**Piezoresistive**	*Source*
--- Planar	**Thermal**	*Power Dissipation*
--- Si Etching &	Magnetic	*Management*
Machining	Piezoelectric	*Noise and Signals*
Non-Photographic	Resonant	*Sources*
(Serial)	Tunneling	*Limits*
--- Non-planar, 3D	Optical/Radiative	*Communication*
--- Standard	Others	*Testing & Calibration*
Precision	**Sensors**	*Integration*
Machining	**Actuators**	*Packaging*

LEGEND:
Bold --- Introduction to MEMS (EECS 414)
Plain --- Advanced MEMS Devices and Technologies (EECS 514)
Italic --- Advanced Integrated Microsystems (EECS 515)

Distance Education Features: EECS 414 uses a high-quality video/audio dissemination of its course materials, initially with high-cost. The class meets in a classroom equipped as a broadcast studio with lighting, quality audio and video recording, and multiple cameras and microphones. The course materials and streaming video are posted to the class web-site about one hour after the "live" class session. Over the last year, the cost to the WIMS Center was reduced considerably and the cost approaches the lower-cost methods that are used for EECS 514 and 515.

INTEGRATED MICROSYSTEMS LABORATORY (EECS 425)

In the course EECS 425 *Integrated Microsystems Laboratory* at the University of Michigan (UM), students work in teams to develop a microsystem of their choice, typically consisting of a two-chip combo: a transducer chip and a circuit chip [3]. Students go from defining a concept, through design, fabrication, and testing in a 14-week one semester course: six weeks are spent in microsystem design, five weeks in fabrication, and three weeks in testing. It allows students to understand the interactions among design, fabrication, and test. For many students, this course is the only chance they will ever have to take a chip all the way from inception to final test. Fig. 3 shows the activity flow for the course, consisting of two 80-minute lectures per week plus one 3-hour laboratory session. The course serves as a major design experience for undergraduates. Enrollment has grown consistently since its inception as an integrated microsystems course, rising from 13 in 2001 to 49 in 2008; now the hard limit is lab facilities constraints.

For the circuitry, a five-mask ion-implanted silicon-gate LOCOS E/D NMOS process is used because it exposes students to a full range of process steps and can be run in five weeks or less. For the transducers, a silicon-on-glass (dissolved-wafer) process is used, allowing a wide range of devices to be realized in six masks and allows wafer bonding and diffused etch-stops to be illustrated. Students are given the processes and a 2mm x 2mm die area for each chip and are challenged to get the best performance they can from their design. Mask fabrication and ion implantation are done in foundries; processes involving chemical vapor deposition (CVD) are done by process engineers of the Michigan Lurie Nanofabrication Facility (LNF), with students performing all other processing steps. Visible imagers, pressure sensors, accelerometers, g-

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switches, tactile imagers, microflowmeters, micro-mirror arrays, mass sensors, Pirani gauges, and resonators have been realized.

Distance Education Features: The lectures are recorded and available online, permitting the course to be taken at other universities (currently Michigan State and Michigan Tech) with an on-site instructor. As a lab course, special arrangements permit students at all locations to have reasonably equivalent access to fabrication equipment. Designs created by students at MSU and MTU are fabricated at UM using process equipment and technical staff of the Lurie Nanofabrication Facility (LNF), and are then returned to them for testing. During those fabrication weeks, MSU and MTU students fabricate other devices in their own laboratories. Some of the fabrication steps have been recorded for sharing at other universities and industry. Methods are being explored to port this laboratory based course (EECS 425). Rochester Institute of Technology has adopted portions of this course, adapted to their fabrication process capabilities.

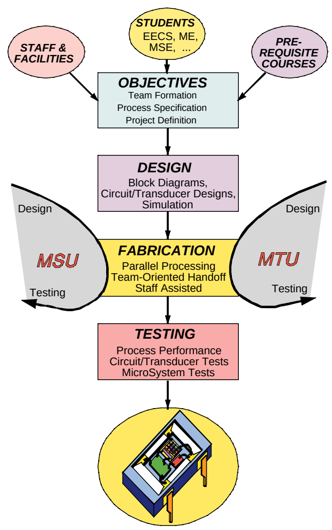

Fig. 3. Activity Flow for Integrated Microsystems Laboratory (EECS 425)

ADVANCED MEMS DEVICES AND TECHNOLOGIES (EECS 514)

EECS 514 is largely an Advanced MEMS Technologies course as it continues the MEMS topics started in EECS 414, as indicated in the Table 1 list of topics. EECS 514 covers advanced topics dealing with MEMS technologies, transduction mechanisms, and microfabricated sensors and actuators. Many emerging micromachining technologies, such as laser and electro-discharge micromachining, and non-conventional materials, such as silicon-carbide and diamond are discussed. Transduction techniques, including electromagnetic, piezoelectric, resonant, tunneling, and others are presented.

The course reviews different types of sensors for measurement of physical parameters such as acceleration, rotation rate, and pressure, as well as chemical and gaseous parameters for gas and chemical sensing applications. It also reviews different micro-actuation techniques and their application in MEMS. The course also reviews MEMS for use in microfluidics and in biomedical applications. An important part of this course is a design project carried out in teams who develop, simulate, and design a device of their choice, and present their findings in a technical article. MEMS-specific CAD tools such as Coventorware and ANSYS are used to design and model the devices. The course is highly structured, with two intermediate presentations and a final one at the end of the course. Typically, students read 25 to 40 papers [12]–[14], and 6 to 8 student reports. A highlight assignment is students working in teams to develop sensor or actuator concept MEMS; see Ref. [4][9] for a sample of concept projects.

Distance Education Features: All course materials, including lecture notes and lecture videos, are available via the web-based University of Michigan CTools system (the second distance education dissemination model).

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ADVANCED INTEGRATED MICROSYSTEMS (EECS 515)

EECS 515 is an Advanced Integrated Microsystems course, building upon the MEMS topics and microsystems introduction presented in EECS 414. EECS 515 is the third in the 414, 514, 515 trio of courses; as such, it is directed primarily at graduate students and industry professionals who have already achieved a level of comfort with MEMS technology, and are familiar with the important transduction methods, device concepts, and fabrication techniques. The students are also expected to have a working knowledge of basic analog circuits. As in EECS 514, students read 25 to 40 papers [12]–[14], and 6 to 8 student reports. For EECS 515, a highlight assignment is students doing an NSF-style proposal centered on a microsystem design to solve an application; see Ref. [4][9] for microsystem design templates.

The topics covered in this course are a mix of device and circuit issues that are closely inter-related and are critical to a full understanding of microsystems. They include, for example, general ways to analyze noise in electronics and sensors; various kinds of interface circuits for capacitive, resistive, tunneling and other kinds of sensors; proportional integral controllers; dithering and modulating circuits; switched-capacitor interface circuits; correlated double-sampling; calibration schemes; system organization; digital bus protocols for transducer systems; packaging; and cost projections. The topics are relevant to both industrial practice and microsystems research, and address both fundamental and practical problems that arise in this field of engineering. An important part of this course is the team project, which requires students to develop research proposals that are then reviewed by the class in NSF-style panels, using both technical merit and broader impact as evaluation criteria. The students are encouraged to think of the strategic end goals, and determine the best minimum set of calculations, simulations, and analysis to address them. The proposals are required to include systems aspects, and thus must cover a circuit in addition to a sensor or actuator. Budgeting and milestone planning for the proposed work are required.

Distance Education Features: All course materials, including lecture notes and lecture videos, are available via the web-based University of Michigan CTools system (the second distance education dissemination model).

SOCIETAL IMPACT OF MICROSYSTEMS (EECS 830)

During the next two decades, microsystems are expected to have a pervasive impact on society as they are used to couple electronics to the non-electronic world. Microsystems will be used to monitor our environment (global warming, pollution, improved weather forecasting), provide homeland security, improve transportation systems (vehicles and infrastructure), and spark dramatic progress in health care (genetics, proteomics, wearable and implantable microsystems for diagnostic and therapeutic use). This course explores the societal challenges that will be faced by our present engineering students during their careers and how microsystems can be used to address them. As a two credit-hour course, the class meets once per week in a two-hour session; the basic format is an hour-long (invited) seminar presentation followed by an hour of questions and discussion.

Seminar speakers have included former astronauts, experts on transportation and global warming, and industrial and governmental leaders in the area of health care. Topics have included clean air, clean water, homeland security, manufacturing, global warming, population growth and its implications, nanotechnology, space exploration, and medical implants, as well as engineering ethics. Students have regular homework assignments and select a topic of interest to them on which to do a term report. These oral reports have been very successful in allowing fascinating looks at many additional topics. In addition to societal challenges, the course also offers the opportunity to examine pioneers in electronics, from Benjamin Franklin to Robert Noyce, to obtain insight into the origins of innovation and the challenges faced in the past. The designated textbook is *Engineering Tomorrow* [15].

Distance Education Features: EECS 830 uses the same high-quality methods as those for EECS 414.

DISTANCE EDUCATION FOR OTHER WIMS COURSES

At Michigan Tech, a course *Micromanufacturing Processes* (MTU MEEM 4640/5640) is a technical elective from a mechanical engineering perspective, developing a broader perspective to students in the program. Course topics include: Scaling analysis, micrometrology methods and instruments, precision

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measurements and practices, lithographic processes, diamond machining, micromilling, microdrilling, micro EDM (electrical discharge machining), and analytical modeling of processes and normal practices. The course originates at MTU, and is disseminated to the WIMS core partners, MSU and UM.

COURSE ENROLLMENTS

Enrollment in each course has been consistently high. Except for the societal impact seminar course, each course is offered once per year, thereby attracting a renewed student population each year. EECS 414 is a door-opener course, one that permits many students to get a glimpse of the MEMS and Microsystems area. Its enrollment numbers have ranged from 57 to 104 students at UM, plus about 50 to 90 students total at all USA distance education remote sites. The undergraduate-to-graduate student ratio is now about 2:1, different from the first years of the course that had a ratio about 1:2. This trend clearly indicates the growing interest in MEMS as a discipline often required by industry, as well as the student assessment of acceptable to high rating of the course and teacher (among the best in the EECS Department at UM). EECS 425 is likewise a pseudo-door opener course, attractive because of its MEMS/Microsystems content and its ABET satisfying capstone major design experience. EECS 425 enrollment is limited by laboratory space capability. Table 2 has enrollment history since the inception of the MEMS and Microsystems curriculum. For each course, two numbers are provided: the first number is the enrollment of local students at the originating university; the second number is the enrollment of distance education students (remote students, industry professionals, etc).

Table 2. Enrollment History for MEMS/Microsystems Courses

Acad.Year➔	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
EECS 414		**57 + 25**	66 + 23	104 + 45	77 + 50	83 + 51	111 + 90	81 + 92
EECS 425	13 + NA	**26 + 16**	31 + 16	42 + 7	39 + 5	48 + 13	50 + 11	32 + 8
EECS 514			**30 + 6**	16 + 6	25 + 18	29 + 13	29 + 2	10 + 3
EECS 515				**17 + 2**	14 + 3	10 + 4	24 + 3	18 + 3
EECS 830			**21 + 10**		18 + 5			

LEGEND:
Enrollments are listed in the format: UM + Distance Education
Bold numbers are first time course in MEMS/Microsystems curriculum
Until 2001, EECS 425 was 3-credits *Integrated Circuits Lab course;* now EECS 425 is 4-Credits Integrated Microsystems Design course; a new and smaller lab facility was used during Winter Term 2008.

MASTER OF ENGINEERING IN INTEGRATED MICROSYSTEMS DEGREE PROGRAM

The development of the core curriculum also led to the establishment of a Master of Engineering (M.Eng.) degree in Integrated Microsystems. The degree program is tailored for industrial participants – practicing engineers and scientists – and accommodates students and industry professionals with a wide variety of backgrounds in engineering, basic sciences, and industry manufacturing and management. The Master of Engineering in Integrated Microsystems is intended as a Professional degree, built around interdisciplinary courses in microelectronics, MEMS, microsystems, circuits, fabrication technology, product development, manufacturing, business and management. The M.Eng. degree differs from the regular master's degree (MS or MSE), having course options in management and manufacturing, and also a practicum with industrial mentor. We believe it is the only University-offered M.Eng. degree in MEMS and Integrated Microsystems.

The requirements of this program include the core courses, technical electives, breadth electives, and an industry-oriented team project. Enumerated, the M.Eng. degree requirements are:

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B.S. degree in engineering, science or mathematics
30 credit hour stand-alone degree program
12 Credit Hours of Required **Technical Depth** Core Course Work –
Required Courses: EECS 414 EECS 514 EECS 515
6 to 8 Credit Hours of **Technical Breadth** Course Work
Electives, such as EECS 425 EECS 511 (Data Converters) EECS 509 (BioMEMS)
5 to 8 Credit Hours of **Manage't, Prod.-Develop't, Manufact'g-Process, Economic-Factors** Csewrk
Required: EECS 830 or equivalent Electives: Other Courses
4 to 6 Credit Hours for **Design Team Project**
Design Project is Motivated by Industrial Application
(Practicum; team is **student**, **faculty**, and **industrial mentor**)

The technical electives include courses in fabrication technology, integrated circuits, RF MEMS and wireless communication, optical MEMS, microfluidics, BioMEMS, and environmental sensing. The breadth electives include manufacturing, management, quality engineering, financial analysis and other industry-relevant courses. The industry-oriented team project partners the student with a faculty member and industry practicing professional mentor in a project suggested by an industrial application. The team project is a very effective way to increase interactions and expose students to real-world applications and problems. Degree approval was secured at UM in 2002. MTU already had a generic Master of Engineering degree program. The core and augmenting courses are a rich set for on-campus students and industry professionals to custom tailor a total course package (to serve individual preferences) for a Master of Engineering in Integrated Microsystems degree program.

Distance Education Features: Taking courses part-time over the web, the Integrated Microsystems M.Eng. degree can be completed in twenty months. The UM College of Engineering through its InterPro (Interdisciplinary Professional Programs) office has assured that the required and elective courses that are needed to complete this degree program in two years will be available as online distance education courses.

CERTIFICATE PROGRAM IN INTEGRATED MICROSYSTEMS

The core and augmenting courses, and highly determined WIMS faculty, facilitate another opportunity to serve industry professionals. The certificate program is intended to serve industry professionals who have high interest to become familiar with the areas of MEMS and microsystems, but have low capability to commit to a two-year (or more) schedule for an online degree program such as the M.Eng. degree in Integrated Microsystems. The certificate program is a first at the University of Michigan College of Engineering, and was approved as a professional interdisciplinary program in 2006 (less than a year ago). The program official title is: Certificate of Advanced Studies in Engineering (CASE) in Integrated Microsystems. Enumerated, the Certificate program requirements are:

B.S. degree in engineering, science or mathematics
15 credit hours, with at least 8 credits at 500 level or above
One course from List A, one course from List B, and the remaining credits from List C

List A Courses

EECS 414	*Introduction to MEMS*	4 Credit-Hours
EECS 413	*Monolithic Amplifier Circuits*	4 Credit-Hours
EECS 425	*Integrated Microsystems Laboratory*	4 Credit-Hours
ME 553	*Microelectromechanical Systems*	3 Credit-Hours

List B Courses

EECS 509	*BioMEMS*	3 Credit-Hours
EECS 511	*Integrated Analog/Digital Interface Circuits*	4 Credit-Hours
EECS 514	*Advanced MEMS Devices and Technologies*	4 Credit-Hours
EECS 515	*Advanced Integrated Microsystems*	4 Credit-Hours
EECS 522	*Analog Integrated Circuits*	4 Credit-Hours
EECS 523	*Digital Integrated Technologies*	4 Credit-Hours

List C Courses

Regular M.Eng. in Integrated Microsystems Courses 9 – 7 Credit-Hours

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Distance Education Features: Taking courses over the web, the Integrated Microsystems Certificate can be completed in one to two years. Many of these courses are a subset of the M.Eng. degree program, though broader electives.

SUMMARY AND COMMENTS

The Engineering Research Center for Wireless Integrated MicroSystems (WIMS ERC) has developed five core courses (Fig. 2) that provide a broad comprehensive curriculum in MEMS and microsystems and that are disseminated internationally by distance education. The course materials have been generously shared, delivered either as a whole course, or as portions of course materials to faculty who decide to teach the course at their home university to further their own course offerings. Several renowned faculty contributed to the development of the courses and course materials. Upper-level undergraduate students, graduate students, and industry professionals from engineering (electrical, computer, mechanical, biomedical, chemical, aerospace) and science (physics, chemistry, applied physics) have enrolled in the courses. Course enrollments have been consistently high. In addition to courses via distance education, students able to complete Master of Engineering degree and Certificate programs in Integrated Microsystems via distance education. Courses such as these and their online distance education availability are changing the culture of engineering education.

ACKNOWLEDGEMENTS

The Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9986866, wholly or partly, supports the WIMS Education program and projects. Professors Gianchandani, Najafi, and Wise provided leadership and educational commitment (with positive intentions in the design and follow-through) to develop, disseminate, and share course materials (distance education). They were the engine to make the process go! This author is simply a messenger.

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