THE CLASSROOM OF THE FUTURE: AN INTERNET-DELIVERED NATIONAL COURSE ON THERMAL MANAGEMENT OF ELECTRONICS

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Teaching inter-disciplinary material poses special challenges due to the diverse background of students in class. This problem is compounded if the material being taught is meant to be suitable for both undergraduate and graduate students. Mechanical Engineering faculty members from three universities have come together to overcome this problem using a layered, multimedia delivery mechanism via the internet. This has resulted in the first-ever, live, full-duplex, internet course taught at any of the three partner universities; Auburn University, the University of Maryland, and the University of Minnesota. With the addition of colleagues from industrial sites such as Philips in the Netherlands and three other universities in Japan, Singapore, and Australia, the next offering will expand to become an international course. The authors hope to convey that a course delivered over the internet adds tremendously to the learning process in a cost-effective manner.

INTRODUCTION

Rapid advances in electronics manufacturing processes have led to continuing increases in the number of transistors that can be integrated on to a single chip. Dissipating the heat that is generated in this very small region is an increasingly complex problem. Thermal management of electronics is an area of study that encompasses knowledge from subject areas that include heat transfer, stress analysis, reliability, circuit design, and the integrated circuit manufacturing process. Teaching this complex subject matter requires the use of non-traditional teaching methods. It is widely recognized that advanced engineering students are quite capable of self-learning if the material is presented in a structured environment. Multimedia tools prevalent on the internet can be used to provide an asynchronous self-learning environment.

IMPLEMENTATION

The course was taught during Winter Quarter 1999 to students at four sites; three sites located at the three partner universities, and the fourth at an industrial location – Lockheed-Martin Tactical Defense Systems, in Eagan, Minnesota. The interaction between the different sites is shown in Figure 1, which also lists the students that participated. The unique interaction with a fifth site shown in Figure 1 will be described later in this paper.

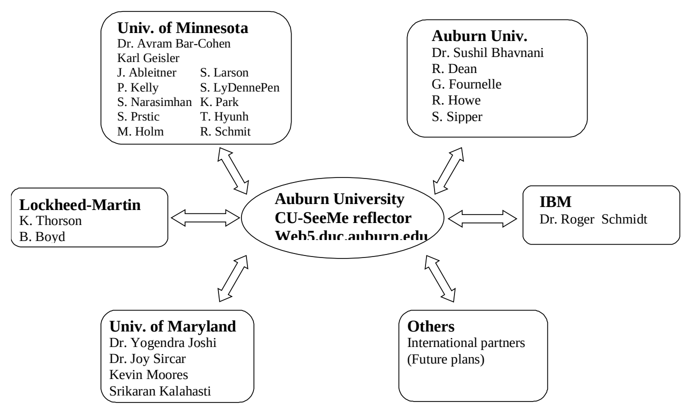

Figure 1. Internet Video-conferencing Network

The commercially available video-conferencing software package CU-SeeMe® was used along with appropriate video-cards and a video camera. The low price of these components (all for under $200 total) should make this format easy to implement at other universities too. The video-conference was facilitated through the Auburn University reflector. The images originated at the University of Minnesota were captured with TV cameras, normally used for broadcasting courses through the University's RF link, and the signal was then converted to a form suitable for internet transmission. As can be seen from the following list, the minimum computational platform requirements are quite modest.

Hardware requirements

Intel Pentium® PC:

- 166 MHz with 32 MB RAM
- 6 MB free hard disk space
- Full Duplex sound card
- Windows 95/98/NT
- Ethernet®/LAN connection preferred
- a camera w/microphone (example: Logitech Quickcam®)
- software, White Pine CU-SeeMe® - http://www.wpine.com/ (allows 8 sites to be connected at a time)
- speakers

COURSE STRUCTURE

The class was held between 6:00 p.m and 9:00 p.m., Central Time every Thursday. This was done in order to avoid scheduling conflicts among the various sites. The course was formatted as follows:

Class time: new pedagogical material, followed by discussion of homework assignments and case studies

Work load: 25 pages of reading per week, 1-2 hours of pre-recorded lecture viewing (asynchronously via internet streaming video), one exam, nine homework assignments, three engineering case studies

Grade: 45%, three written case study reports and presentations; 20% take-home final exam; 25% homework; 10% class participation. (Exam format: solving design problems)

Modular Design

A typical class began with some new pedagogical material delivered through PowerPoint® modules that were accessible to all students at every site through the course web-site. Background information for each class was communicated through streaming video modules, developed at the partner universities, which were also accessed by students through the course web-site. This modular approach is a major strength of the course allowing selected parts of the course material to be used in other courses in the future.

The modules used in the course are listed in Table 1. The choice of module topics was dictated by the expertise and research interests of the team (Joshi et al., 1999) and included conduction in chip packages and printed circuit boards, air and liquid cooling, computational fluid dynamics modeling, micro-fabrication techniques, and fin optimization. These are some of the areas of greatest current interest in electronics thermal management.

Examples of modules developed by the participating institutions are:

- **Computational Analysis of Heat Transfer in Packaging Configurations**

This module includes tutorial information on computational fluid dynamics/heat transfer theory and applications. The primitive-variables based finite volume formulation is explained and illustrated through examples. The examples, drawn from research projects conducted at the University of Maryland, include natural and forced convection cooled electronic enclosures and use of solid-liquid phase change materials (PCM) for electronics thermal control. The transient results for the latter example are presented as animations. Key considerations in the use of computational techniques are discussed. The background and application details associated with each example are also included. An example of a computational fluid dynamics/heat transfer application included as part of the module is presented in Figure 2.

Table 1. Course Modules

Module 1.	Semiconductor Packaging Trends/Options
Module 2.	Review of Heat Transfer Principles
Module 3.	Reliability of Electronic Systems
Module 4.	Chip Package Thermal Characterization
Module 5.	Conduction in Printed Circuit Boards
Module 6.	Convection from Printed Circuit Boards
Module 7.	Computational Analysis of Heat Transfer in Packaging Configurations
Module 8.	Design/Optimization of Single Fins
Module 9.	Design/Optimization of Heat Sinks
Module 10.	Micro-fabrication Techniques
Module 11.	Heat Pipes in Packaging Applications
Module 12.	Direct Liquid Cooling

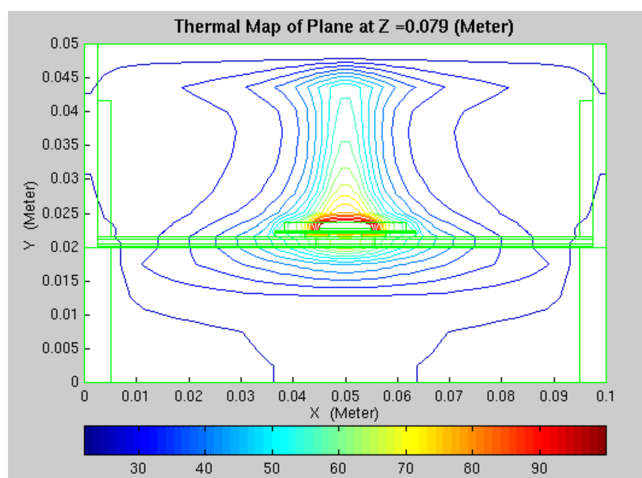

Figure 2. Examples of temperature contours above a chip in an automotive electronics module. Computations have been carried out using a module developed as part of the National Course effort.

- **Micro-fabrication Techniques**

The continuing growth of the microelectronics industry is contingent in part upon the heat dissipation methods used for microelectronic circuits. Consequently, thermal management is an area of the industry that is growing in importance. Constructing heat sinks in silicon is one possible means of achieving better performance. For this reason, circuit designers as well as thermal designers need to understand the microelectronic fabrication sequence used for fabricating circuits and heat sinks. This module leads students through the steps in a typical microelectronics fabrication sequence. The module is built around equipment available in the Alabama Microelectronics Science and Technology Center, an on-campus facility at Auburn University. The module consists of video/audio clips that familiarize students with equipment used in the key stages of microelectronics fabrication. The layout, photolithography, masking, and etching processes (browser image shown in Figure 3) used to fabricate heat sinks are very similar to those used to fabricate the integrated circuitry itself. Animations built into the module serve to illustrate these processes. In Figure 3 the window in the upper left-hand quadrant is triggered by passing the mouse over text in the main document, and yields additional information on the highlighted text.

Figure 3. Browser image indicating a portion of the virtual fabrication laboratory tour.

- **Direct Liquid Cooling**

This video module, developed at the University of Minnesota, includes a comprehensive presentation of fundamentals and applications of direct liquid cooling. The extremely high thermal performance associated with this mode of cooling makes it an attractive option for many current and future technologies. The module discusses natural and forced convection liquid cooling schemes, as well as phase change based schemes. The extensive research in these areas carried out during the past twenty years is summarized. Correlating equations for heat transfer under the various regimes are presented. Implementations of liquid cooling in a number of electronic systems are discussed.

The Layered Approach

Prior to each class, students were expected to view background material in the form of streaming video modules downloadable from the course web-site. Class time commenced with the introduction of new material, following which students at various locations were called on to present their homework/case study solutions to the rest of the virtual classroom. Student solutions, submitted electronically the previous day, were made available for viewing on the course web-site allowing all other students to view the presentation materials as they were being discussed. The three-hour segment usually ended with either an introduction to the next homework example/case study, or with additional new material. It was very empowering to both students and faculty to have the capability of carrying out a live discussion between sites, at any point during the course. Figure 4 shows a typical class in progress with students at two sites watching and listening to students at a third site demonstrate the characteristics of the thermal management strategies used in a typical PC. The chat screen at the bottom facilitated communication secondary to the class discussion. Up to eight sites can have full duplex audio-video connections using the CU-SeeMe® multimedia application.

Figure 4. A CU-SeeMe® image of the course in progress. Up to eight sites can be connected using this tool.

Case Studies

The case studies chosen deserve special mention. All cases studied were feature-rich, drawn from actual current practice, and open ended (Bar-Cohen, et al., 1999). The first case study discussed dealt with a leading-edge packaging technology, the second with a current NSF Research Center project on next-generation electronics packaging technology, and the third with an industrial product (see Table 2). The industry problem chosen was a new IBM server cooling module shipped towards the end of 1998. Figure 5 shows the subject of this case study. The final class of the term featured the IBM designer (see Figure 1) of this product speaking with students at all sites via a live audio hook-up. This guest speaker also served as a "judge" critiquing the case study results as they were being presented. This contact with industry helped motivate the students even further, underlining the relevance of the course material.

Table 2. Case Studies used in the Course

1. Thermal Packaging of Direct Chip Attach
2. Limits in Air-Cooling of Single Level Integrated Module Packaging Technology
3. IBM Refrigeration Cooled Server

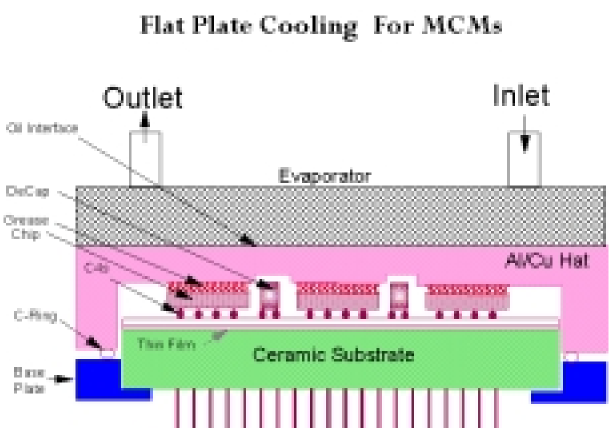

Figure 5. Schematic of the multi-chip module of the IBM refrigerated server unit

TEETHING TROUBLES

As is to be expected when working with new technology, there were a few things that did not work perfectly. There were occasions during the course when students at some sites would briefly lose track of the specific slide that was being discussed by the instructor. In these situations, the chat screen portion of CU-SeeMe® that accompanies the video-screen was used by the graduate teaching assistant to help redirect remote sites.

The three-hour long format was perhaps not best-suited to a class such as this that does not involve eye-to-eye contact. A shorter, more traditional format might have worked better, although the longer format did help provide a more in-depth discussion of case studies.

FUTURE PLANS

Immediate plans call for a second offering of this course to be implemented in January 2000. The scope will be broadened to include colleagues in several other countries as well (despite the attendant time zone related scheduling problems). Response thus far has been enthusiastic and plans are underway.

An eventual goal is to steer this material towards a user-selected compilation of modules available in electronic format (a set of CD-ROMs) along with an instructor's guide to allow the use of the modular material in a flexible fashion. The modules could also be used as part of a packaging course, as part of a heat transfer or fluid mechanics course, or by a EE graduate student who needs to know something more about PCB conduction or heat sinks.

Finally, although this model, in the view of the authors is representative of the classroom of the future, there will always be a need for more traditional student-to-professor interaction in courses earlier in the engineering curriculum. For this reason, worries about the demise of the professoriate are entirely too premature!

SUMMARY

In summary, this first offering of an internet-delivered national course on thermal management has been an enormous success. The availability of inexpensive internet tools makes this delivery mechanism extremely viable for a vast array of courses. The authors hope to use this ASME forum to disseminate information on the methodologies used, and the journey up the learning curve that led to a successful implementation. The authors would like to suggest that readers visit the course web-site at http://www.me.umn.edu/courses/me5345/

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