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A Thermal Management of Electronics Course and Laboratory for Undergraduates

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ABSTRACT

A novel thermal management of electronics course with an associated laboratory has been developed for mechanical, electrical, and computer engineering students. The lecture topics, term project, computer modeling project, and six associated experiments that were built from scratch are described. Over half of the course lectures as well as all lab manuals and project information are made available via the course website. Pre- and post- tests were performed and analyzed using a t-test and showed a significant increase in student understanding in fundamental thermal management problems.

Keywords: electronics cooling, education, student experiments

I. INTRODUCTION

The cooling of electronics has emerged as a challenging and constraining problem during the last several decades. The economic market demands ever faster clock speeds and simultaneously smaller physical enclosures. Since computer chip heat fluxes (rate of heat transfer per unit area) increase with increasing clock speeds and decreasing chip sizes, these demands have led to skyrocketing heat flux removal demands. Indeed, the famous Moore's Law, which predicted a doubling of the number of transistors on a chip every two years, has held true since its inception in 1965. Transistors in current applications are as small as 45 nm [1]. At the same time, current technology continues to require a low junction temperature (typically of no more than 125°C [2], but which varies widely with application). Above this maximum temperature, the lifespan of the chip decreases significantly. The challenges posed by increasing chip heat fluxes, smaller enclosures, and stricter performance and reliability standards have made thermal management of electronics a vital technology in the continued development of 21st century microelectronic systems [3]. Indeed, thermal management of many systems that are likely to be developed in the next several years cannot be done with the current state of technology [4].

In the early 1960's, heat removal rates ranged typically from 0.1 to 0.3 W. Air cooling was and still is the most common technique used to cool electronics. Innovative air cooling techniques allowed heat dissipation rates of 60–70 W by the late 1990s [3]. However, many industries have had to begin looking to high-capacity cooling technologies rather than air cooling. Liquid cooling, has been used for many years by such companies as Cray (using immersion in liquid nitrogen) and IBM and Honeywell (in their water-cooled mainframes) but is receiving increased interest for more widespread applications. Technologies receiving a lot of interest include liquid cooling using microchannel heat exchangers or microchannels etched into silicon, heat pipes (already used heavily in laptops and many non-electronics applications) and thermo-electric devices. Whatever the methodology, cooling must be a part of an integrated, chip-to-system design for many new systems [2].

Who will perform these integrated designs and develop the next-generation cooling systems? Undergraduate mechanical engineering curricula include a class on heat transfer, but the cooling of electronics typically receives limited attention. Some electrical engineering curricula now include a course in heat transfer, but these courses by necessity emphasize fundamentals without in-depth analysis of electrical systems or laboratory work. Most industrial work in this area is performed by engineers with advanced degrees and/or significant training on-the-job. Some universities (such as Stanford and Maryland) offer classes on electronics cooling at the graduate level. Only a few universities (such as Purdue, Minnesota, and UC Berkeley), offer classes specifically devoted to thermal management of electronics for undergraduates or jointly for graduate and undergraduate students. None have a laboratory devoted to thermal management of electronics for undergraduate students (that the authors could find) [5].

The need for engineers equipped to handle thermal management problems is especially significant in the Silicon Valley where San Jose State University is located, a need which is only going to increase. Therefore, a curriculum devoted to the thermal management of electronics at the undergraduate level has been developed with funding from the National Science Foundation. The objective of this paper is to present readers with a comprehensive lecture/laboratory course that familiarizes undergraduate engineering students with relevant techniques for thermal management of electronic devices of the present and those in the immediate future and to make lecture and lab materials available to other schools.

This curriculum provides students with an understanding of current and emerging cooling technologies and appropriate experimental methods, giving them the background they need to either work exclusively in the thermal management field or work as electronics designers who know how to deal with thermal issues. The curriculum has two main aspects. First, a laboratory has been developed that can be used in several classes taken by mechanical, electrical, and computer engineering students. Second, a new senior-level elective open to these students has been developed. This elective focuses on an overview of the problems of electronics cooling in general, air-cooling technologies, computational design methodologies, standards developed by JEDEC (the leading developer of standards for the solid-state industry—the acronym no longer officially stands for anything), and emerging technologies, including cooling of nanoscale devices. It includes both lecture and a significant laboratory component.

The laboratory includes six experiments plus computational capabilities. Experiments focus on 1) temperature measurement methods, including uncertainty, 2) chassis impedance and fan performance, 3) thermal resistance measurements in an air-cooled computer, 4) heat sink performance, 5) heat pipes, and 6) thermo-electric cooling. These experiments and computational fluid dynamics (CFD) capabilities provide students with a broad overview of techniques and technologies used in industry. The course and these experiments are described below, followed by an assessment of results of the first course offering.

II. NEW ELECTIVE: THERMAL MANAGEMENT OF ELECTRONICS

A. Course Overview

This elective course is open to mechanical and aerospace engineering students who have completed the undergraduate heat transfer class and electrical and computer engineering students who have completed the required introductory electronics cooling course. It covers an overview of the problems of electronics cooling in general, air cooling, computer modeling, fundamental convection issues, JEDEC standards, and other technologies. Table 1 gives an overview of the course topics. It includes revisions made after the first offering of the course in Fall 2006 and thus does not fully match the schedule given on the course website (discussed below). The course includes two hours of lecture and two or three hours of lab per week, providing students with a comprehensive understanding of the cooling of electronics as well as experimental methods. The students completing this class are uniquely situated to begin jobs in thermal management in a variety of industries.

A detailed course syllabus along with many of the PowerPoint presentations used in class are available for download on the course website: http://www.engr.sjsu.edu/ndejong/ME_146.htm [6].

Section	Lecture Topics	Experiments	Time
Introduction	1. Overview of electronics cooling problems	1. Intro to temperature measurements	1 Week
Air Cooling	1. Thermal resistance method 2. Heat transfer review 3. Fan performance 4. Heat sinks	1. Fan/chassis impedance curves 2. 1-D thermal resistance 3. Heat sink testing	3 Weeks
Computational Methods	1. Development of CFD models and analysis of results	1. Flotherm tutorial	1/2 Week
Misc. Issues	1. Thermal interface materials 2. Constriction/spreading resistance 3. Thermal stress 4. Data center HVAC 5. RoHS Compliance 6. JEDEC standards	none	2 Weeks
Other Technologies	1. Heat Pipes 2. Liquid Cooling 3. Thermo-electrics 4. Vapor-compression 5. Nanoscale heat transfer	1. Heat pipes 2. TECs	6½ Weeks

Table 1. An overview of the lecture topics and laboratory experiments in the new elective.

The course learning objectives are as follows: By the end of the course, each student should demonstrate ability to

Lecture and Lab Introduction

1) Describe the problems associated with high temperatures in electronics.
2) Determine where heat will be generated in a system.
3) Describe the different options for temperature measurement.
4) Construct and calibrate a thermocouple and calculate the uncertainty involved with measurements.

Air Cooling

5) Construct a 1-D thermal resistance network for a system and use it to calculate junction temperatures.
6) Calculate heat transfer coefficients for common air cooling configurations for both forced and natural convection.
7) Estimate heat loss due to radiation.
8) Choose an appropriate heat sink for a system and calculate its thermal resistance.

9) Estimate the pressure drop through a system and choose and locate an optimal fan sufficient to overcome pressure drop.
10) Use an airflow test chamber and manometers to construct chassis impedance and fan performance curves.

Computational Methods

11) Describe issues important to setting up an accurate CFD model.
12) Develop a CFD model of a computer chassis and analyze fluid flow and system temperatures

Miscellaneous Application Issues

13) Calculate the constriction/spreading resistance for a system.
14) Choose a thermal interface material for a system and calculate its thermal resistance.
15) Perform a simplified analysis of induced thermal stresses.
16) Explain what RoHS is and why lead is being removed from electronics (RoHS stands for the restriction of the use of certain hazardous substances in electrical and electronic equipment) [7].
17) Find a JEDEC standard that applies for a particular situation [8].

Other Technologies

18) Calculate heat transfer coefficients for single- and two-phase liquid flow.
19) Describe how a heat pipe works and choose an appropriate heat pipe for a certain design.
20) Describe how a thermoelectric cooler (TEC) works and choose an appropriate TEC for a certain design.
21) Explain how vapor-compression systems are used in the cooling of large-scale electronics.
22) Design and construct a combined air- and liquid-cooled system for a heat source using fans, pumps, and heat sinks
23) Explain how heat transfer is different on nanoscale devices.

Class format includes traditional blackboard use and PowerPoint presentations. However, active and collaborative learning has been shown to increase student learning effectiveness significantly [9–11]. Therefore, these methods are used significantly. In addition to all lab experiences and the group project (discussed under "D"), small active group and individual activities are incorporated throughout the class. For example, the instructor will frequently pose a question to the class, have the students discuss in small groups, and then present their results to the class. Short ungraded quizzes are included during class time to help students determine if they really understand the material. And students frequently work on short theoretical or computational problems in groups during class.

B. Nano-Scale Heat Transfer

The emerging technologies section includes a two-week component on nanoscale heat transfer. As electronics become smaller, it is important that students know at what point traditional heat transfer behavior no longer applies. In a recent textbook published on MEMS design and manufacture [12], Hsu summarized the fundamentals of thermofluid analyses in submicrometer, or nanoscales. Thermal energy transmission in solids at the nanoscale is dominated by the mean free path and mean free time associated with the traveling energy-carrying quanta in the solid. The quanta that contain thermal energy vary with materials—for example, phonons carry energy for dielectric and semiconducting materials, and phonons and electrons do so for metals. As a result, there is no possibility for a traditional steady state thermofluid condition at the nanoscale.

The design and analysis of convection cooling of nanoelectronics systems must include "rarefied gas dynamics" as the principal modeling tool. Furthermore, pertinent thermophysical properties are size-dependent in the nanoscale, which further complicates the analysis. Special techniques available for measuring thermal conductivity and thermal diffusivity of materials at the nanoscale are also included in the lecture. This fundamentally different thermofluid behavior for nanoelectronic systems is introduced in this elective course with examples and illustrations. It is hoped that this introduction will stimulate students' interest, thus motivating them to further studies in follow-up courses and research at a graduate school. The lectures used for this topic are included on the course website.

C. Computational Analysis

Computational modeling is widely used as a design tool. Most companies involved with electronic packaging employ a commercial computer package to assist in system design. No education into electronics cooling will be complete without an introduction to one of these packages along with a discussion of their strengths and weaknesses and associated uncertainty. Therefore, Flotherm, manufactured by Flomerics, Inc., an electronics cooling CFD (computational fluid dynamics) package, is introduced to the students in this new elective course. A tutorial was developed and is used during one of the lab sessions. During Fall 2006, the students also developed their own projects that were completed using Flotherm. However, this proved problematic partly due to problems with software installation but mainly due to the minimal time available for training using the software. Shorter assignments will be developed in the future to introduce the students more fully to the program rather than requiring an independent CFD project.

D. Course Project

The course project is a modification of one developed by Dr. Arun Majumdar at University of California at Berkeley [13]. The goal of this project is to design a sustainable cooling system using provided components that results in the lowest surface temperature possible for a 2.5 cm × 2.5 cm 10 W heat source. A heater is embedded on a bakelite base with a copper plate placed on top of the heater as a heat spreader. A thermocouple is glued to the surface of the copper plate using an epoxy resin. Student teams of three are provided with a small centrifugal pump, an axial fan, some fittings, and rubber tubing. They are allowed to spend up to $20 of their own money, and they may machine anything they would like from scrap metal. Students demonstrate their devices during the class lab session, and they must write a written report that includes the following:

1. Final design description
2. Design justification
3. Estimated copper temperature based on theory
4. Measured copper temperature
5. Discussion of differences between theory and measurement
6. Further discussion of major challenges and recommended design changes
7. Bill of materials

Most of the teams did well in Fall 2006, with an average and median project grade of B+. Cooling schemes implemented included liquid cooling, use of a heat pipe, and air cooling. In the future, the students will be required to turn in the theoretical calculations earlier in the semester (rather than solely with the final report) to make sure that students do not leave the project until the last minute. Because of this tendency to procrastinate, some of the teams did not have enough time to revise their initial design based on the results of their theoretical calculations. A photograph of the "winning" design is shown in Figure 1.

III. LAB EXPERIMENTS

Lab handouts for most of these experiments are available on the course website. Additional information is available by contacting the lead author.

A. Temperature Measurement Laboratory

Engineers working in the thermal area must have an understanding of how to take accurate temperature measurements and for account their uncertainty. This is a topic left out of many heat transfer courses, leaving many engineers with an inadequate understanding of experimental design and data interpretation. The laboratory session provides an overview of temperature measurement devices, teaches the students how to calibrate them, and teaches students how to calculate temperature measurement uncertainty and estimate its value.

This laboratory session begins with a discussion of the performance of common devices including thermocouples, RTDs (resistance temperature devices), and thermisters, including their uncertainty. In this experiment, students make their own thermocouples and calibrate them and then compare

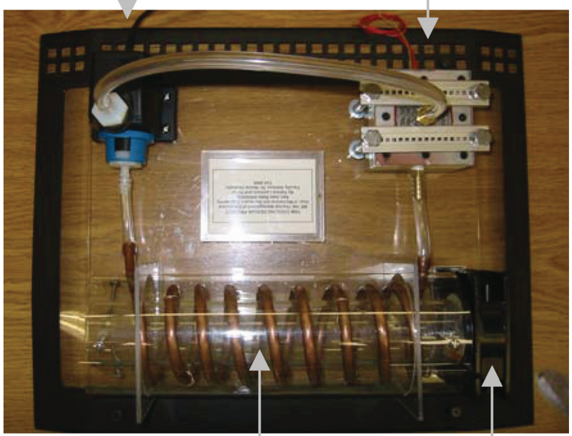

Figure 1. Winning design from Fall 2006 semester. This was a liquid-cooled model.

their accuracy to the accuracy of a pre-made thermocouple connected to a hand-held reader. Their home-made thermocouples are connected to a voltmeter and use an ice-point reference junction. Students develop calibration curves and calculate both bias (fixed) and precision (random) errors. The magnitude of the random error can be defined using a 95% confidence interval for the temperature readings at a given temperature (approximately forty readings are taken for this calculation). This lab helps students gain a better understanding of how temperature is measured electronically, how to determine uncertainty, and how to reduce uncertainty by performing calibrations. A possible extension of this lab would be to include more advanced topics such as optical measurement methods and heat flux measurement devices.

B. Chassis Impedance and Fan Curves

Since most systems are currently cooled using air, it is important that students understand the relationship between fan performance, chassis impedance (resistance to air flow), and system thermal performance. The second experiment, therefore, involves the measurement of system impedance in computer chasses and development of fan curves over a wide air flow range. An AMCA 210-99 Airflow Test Chamber has been acquired from Airflow Measurement Systems; this is industry-standard equipment, and a photograph of the equipment can be seen at http://www.engr.sjsu.edu/ndejong/Electronics_Cooling.htm. Students develop fan curves for a single fan, two fans in parallel, and

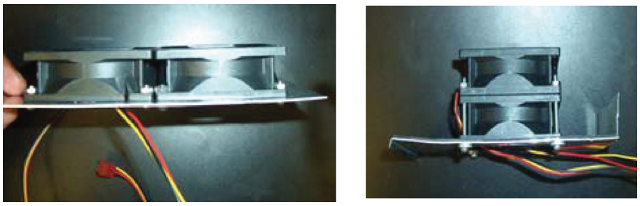

Figure 2. Two fans in parallel (on left) and in series (on right).

Figure 3. Chassis attached to the Airflow Test Chamber.

two fans in series. See Figure 2 for a photograph of two fans in parallel and series. They also measure the system impedance for the computer chassis with both the parallel and series fan configurations and with a vent in the back of the chassis closed (to simulate a chassis with a large amount of flow obstruction) and open (to simulate a chassis with a limited amount of flow obstruction), as shown in Figure 3. Due to limited lab time, each team develops one fan curve and one chassis impedance curve, and then the student teams share data. From the data, students are able to see how system impedance affects air flow. Figure 4 shows the system impedance and fan curves for the parallel fan case.

C. Thermal Resistance Measurements in a Computer

One of the most basic methods used in electronics cooling is the one-dimensional thermal resistance method. Electronic packages are typically rated in terms of their thermal resistance, maximum allowable junction, and power dissipation. In this experiment students measure junction, case, and air temperatures for a known power dissipation in several computer chasses.

Instead of using a computer chip, a small heater is used to model the chip junction. It is surrounded by a metal case, simulating the chip case. A heat sink is placed on the case to aid in heat transfer.

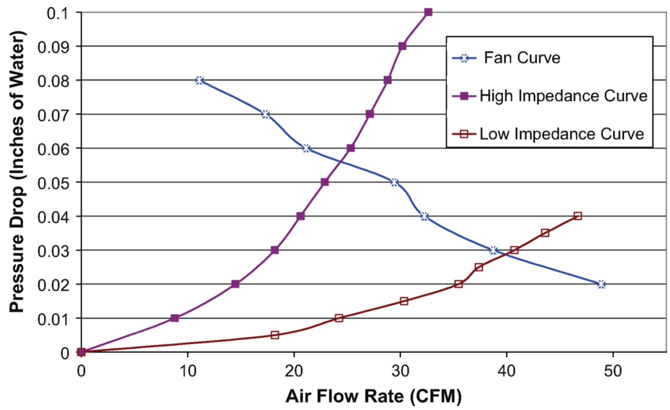

Figure 4. Fan curve and two impedance curves for parallel fans [14].

The junction, case, and air temperatures are measured using thermocouples. The temperature of the bottom of the printed circuit board (PCB) underneath the heater is also measured to help estimate the amount of heat conducted through the printed circuit board rather than through the heat sink. Students calculate the total value of resistance to heat flow from the case to the air as well as the junction-to-case resistance. The students perform this experiment for five different cases: 1) no fans (natural convection), 2) two fans in series, high impedance, 3) two fans in parallel, high impedance, 4) two fans in series, low impedance, and 5) two fans in parallel, low impedance. System impedance is altered by opening and closing a door covering the air vent for the chasses. With fan and chassis impedance curves provided, the students can also determine the effect of air flow rate on thermal performance. Four systems were constructed to allow students to work in groups of three or less.

D. Heat Sink Tester

A small wind tunnel was built to easily test a variety of heat sinks. In this lab, students measure the resistance of four different heat sinks and compare the results to theoretical calculations. A resistance heater is used to model an electronic component. Students measure input power and the temperature of the heat sink base and air for the range of flow rates typical to application. They also measure the temperature drop across insulation underneath the resistance heater to determine heat loss through the bottom of the wind tunnel. To calculate thermal resistance of the heat sink (R_{HS}), they use the equation

$$R_{HS} = \frac{T_{HS\,base} - T_{air}}{Power} \tag{1}$$

where T_{HSbase} is temperature of the heat sink base, T_{air} the air temperature, and *Power* the heat dissipated through the heat sink. Fluid velocity is measured using an orifice plate. Results using the newly developed apparatus had an average difference with theory or published experimental data of 0.8% for a six-fin straight fin heat sink, 6.6% for a thirteen-fin straight fin heat sink, and 10.6% for a pin fin heat sink. An elliptical fin heat sink was also tested, but no data were available for comparison. Students are able to gain experience performing basic heat sink calculations, and the lab also allows them to examine heat sink performance as a function of flow rate and geometry [15].

E. Heat Pipes

In recent years, heat pipes have arisen as a popular method of heat removal in electronics for cases where high heat fluxes or confined spaces make air cooling difficult [16]–[19]. Two short experiments introduce students to how heat pipes work and the high heat removal rates that they can effect. In the first experiment, the evaporator section of a cylindrical heat pipe is placed in hot water, and the condenser section is placed in a wind tunnel. The section in between the water tank and the wind tunnel is insulated. Thermocouples are used to measure the air and condenser surface temperatures in several locations. Using convection heat transfer correlations for external flow over a cylinder and the measured temperatures, the heat removal rate can be determined. A copper rod with the same dimensions is examined in the same way so students can compare the heat pipe performance to the highly conductive copper rod and see how much better the heat pipe performs.

In the second experiment, an old laptop computer that does not use a heat pipe has been instrumented so that students can measure the thermal performance in an actual system. The students must develop a conceptual design, with rough sketches, showing how they could improve the performance of the laptop computer by adding a heat pipe. Both experiments are included in the same lab period as two different stations.

F. Thermoelectric Cooling

Thermoelectric coolers use solid-state technology based on the Peltier effect to pump heat. The cooler includes an array of p- and n- type semiconductors that have been doped with electrical carriers. A full description of how these coolers work can be found in [20] or [21]. The benefits of these coolers are that they are reliable, small, can cool below the ambient, and hold a surface at a very precise temperature. However, their low coefficients of performance are very low, they can only remove low values of heat flux, and one must remove a lot more heat than what one began with, equal to the heat load plus the power input.

In this lab, students compare the surface temperature of a heater (which models an electronic component) with and without a thermoelectric cooler (TEC), for two different power settings. Figure 5 shows a schematic of the setup with a TEC. The thicknesses of the TEC, copper heat spreader, and heater have been increased for the sake of clarity. The TEC, copper, and heater are

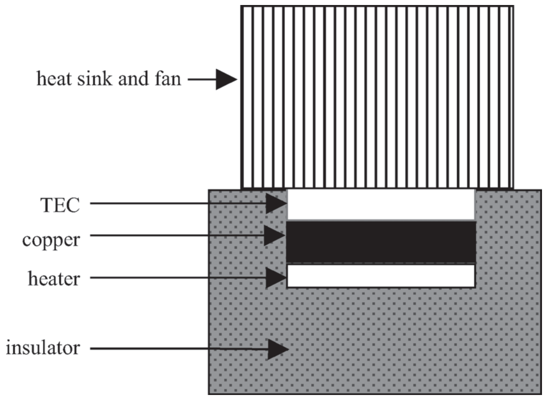

Figure 5. Schematic of experimental setup for the TEC lab.

all very close in size to limit spreading resistance. Four setups were developed: two with 40 W heat sources and two with 10 W heat sources, one with and one without a TEC. Students can vary both fan speed and power input to the TEC.

Students measure power input to the TEC and the heater as well as the temperature difference between the copper heat spreader and the air ($\triangle T$). Students calculate the coefficient of performance (COP) using the simple equation shown below.

$$COP = heater\ power\ removed / TEC\ power\ input \quad (2)$$

In their analysis, students determine the optimum operational TEC voltage for the 10 W and 40 W heaters, compare cooling performance with and without the TEC, compare their plots of COP vs. $\triangle T$ to those developed by the manufacturer, discuss the causes of several unexpected results, and analyze the effect of increasing airflow rate. While class lectures focus on thermoelectric theory, this lab brings a practical component to the class.

IV. COURSE ASSESSMENT

Pre- and post-tests were given to the students at the beginning and end of the semester to gauge changes students' interest in pursuing employment in the area of electronics cooling and their confidence in and understanding of basic electronics cooling concepts. A *t*-test was performed to analyze both the pre- and post-test results to determine statistical significance [22]. A summary of average results are shown in Table 2. Questions shown in the table have been paraphrased for the sake of brevity. Unfortunately, there were only nine students in the class during the first course

Rate your confidence that:	pre-test	post-test	increase (%)	signif-icant?
you will search for a job in electronics cooling (EC)	7.6	7.4	–2	no
you have received a good background for a job in EC	6.3	7.9	26	no
you will succeed in a job in EC	7.9	8.9	13	no
you can use CFD for EC applications	4.7	8.1	72	yes
you can do simple thermal resistance calculations	6.4	9.7	51	yes
you can choose a suitable heat pipe	5.4	7.4	37	no
you can choose a suitable TEC	4.4	8.3	90	yes
you can choose a suitable heat sink	6.9	9.6	40	yes
you can design an air-cooling system for an electronic component	5.8	8.6	48	yes
you can design a liquid-coolingsystem for an electroniccomponent	4.6	7.9	69	yes
Score on Fundamental EC Concepts Quiz	43%	74%	69	yes

Table 2. Average student assessment results before and after completing the course. Here "1" is the lowest possible score and "10" the highest

offering due to a conflict with a required class, so a large increase is required for results to be significant. The surveys will be given again in later semesters to acquire a larger data bank.

Assessment results showed a significant increase in student understanding of electronics cooling issues as well as in student confidence in their ability to perform a variety of tasks. A significant improvement was not seen in students' confidence in their ability to select a heat pipe. An additional course exercise will be added in future semesters to add this more practical skill to the heat pipe fundamentals emphasized in class. The surveys also did not show a significant increase in student interest in pursuing future work in the thermal management area. This may be largely due to the fact that only students who were already interested in the topic chose to take this elective among the many available, especially when a class conflict was present. The course surveys show a high level of student interest both before as well as after the class. Three of the nine students in the class received an internship in thermal management labs in large Silicon Valley companies after completing the course.

V. ALTERNATE COURSE VERSION

During semesters when the first author does not teach the course, two engineers from Hewlett Packard, Cullen Bash and Chandrakant Patel, teach the course. Because they work full time in industry, they bring a unique perspective to the class. However, they also do not have the time to run a full lab. While the lecture content remains similar, they run two lab experiments of their own design during this course. These experiments are described below.

One of the experiments the students are asked to perform is to measure the thermal and flow resistances of a heat sink. This is very similar to the heat sink tester described in Section III D. In this experiment they place a heat sink attached to a heat source in a small wind tunnel. Airflow through the wind tunnel is varied via variable speed DC fans that are connected to a DC power supply. As the students vary the fan speed they record the heat sink thermal resistance and flow resistance (i.e. pressure drop) and graph the resulting data. The students then non-dimensionalize the thermal resistance data to form a relationship between the Nusselt number and Reynolds number. Likewise, they form a similar relationship between the friction factor and Reynolds number using the flow resistance data. Given the dimensionless data, they then describe various phenomena about the flow characteristics like the identification of laminar to turbulent transition. During the experiment they are asked to use the apparatus displayed in Figure 6. This includes guarded

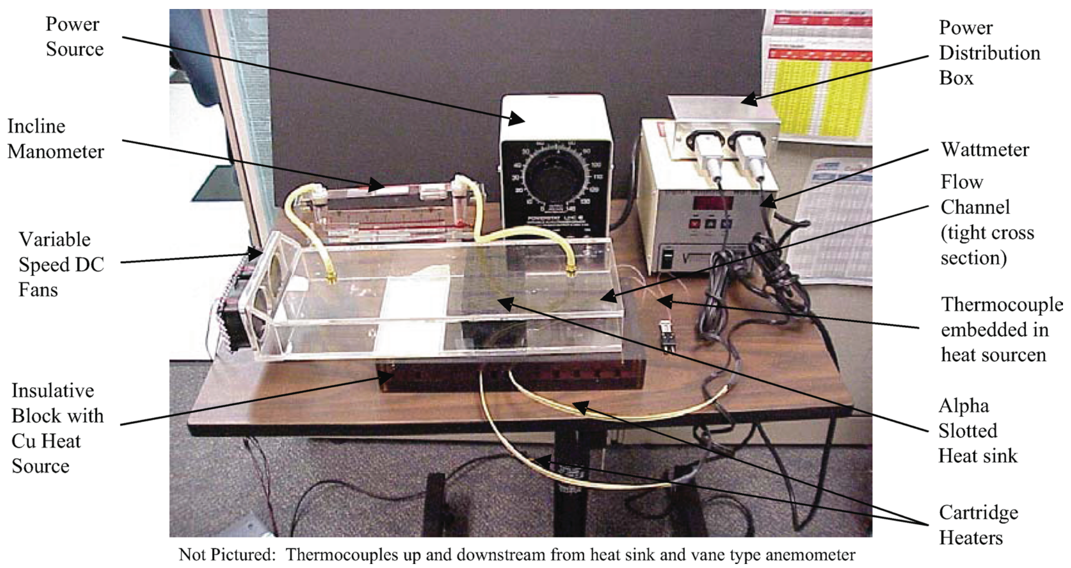

Figure 6. Apparatus used to calculate thermal flow resistances of a heat sink for a range of velocities.

heat sources, power supplies, power meters and temperature sensors for the thermal resistance measurements and incline manometers, vane-type anemometers and wind tunnels for the flow resistance experiments.

A second experiment is conducted that investigates the heat transfer from a vertical aluminum plate compared to a similar plate partially filled with low boiling point fluid to form a thermosyphon. The students attached a heat source and thermocouples to each plate and record the temperature variation at steady state. An infrared thermometer is also used to supplement the data from the thermocouples. After the data are obtained, the conductive thermal resistance of each plate is estimated, and the convective heat transfer efficiency is estimated (via Nusselt number calculations). The students then estimate the total amount of heat transferred via buoyancy induced convection compared with radiation for each plate. The results indicate that the thermosyphon significantly outperforms the solid aluminum plate.

VI. CONCLUSIONS

It was a challenge for the authors to develop this combined lecture/lab course on thermal management of electronic devices and systems covering such a wide spectrum for students from various academic disciplines. The knowledge and experience that they acquire from this course are not only limited to the applications to current electronic systems but also to the technologies for the immediate future. Student pre- and post-tests after the first offering has shown a significant improvement in their understanding of thermal management of electronics fundamentals and confidence in their ability to perform typical related tasks. Although the data collected on students' effective learning was based on a relatively small sample size from the initial offering of the course, a clear positive sign of their learning the subject nevertheless has emerged.

Course materials are available for download on the course website, and additional information is available by contacting the instructor. This arrangement can also benefit practicing engineers in the field of thermal management of electronic devices and systems in their self-learning process.

VII. FUTURE WORK

Nine students is a very small sample size upon which to base assessment. This course will be taught again, and additional data will be acquired.

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