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# Cooling Methods for Electronics Design

Course No. 471

**FOR WHOM INTENDED:** Electronic designers and packaging specialists, environmental test laboratory engineers and technicians, specification writers, equipment designers, and quality and reliability specialists.

**BRIEF COURSE DESCRIPTION:** The course introduces the fundamentals and physics of thermodynamics and heat transfer. The need for thermal management in electronics design is discussed. Next, the basic types of heat transfer, convection, conduction and radiation, are introduced and then discussed in depth. Conduction is covered first, including how thermal resistance and conductivity are calculated and the effect of joints on thermal resistance. Numerous ways of improving thermal conductivity are presented in detail, and examples illustrate and quantify the effects of these methods. Convection topics include free versus forced convection, heat transfer and film coefficients of air and fluids, PC board spacing, heat sinks and impingement cooling. Classroom examples show how to calculate the thermal effects of natural convection, heat sinks, laminar and turbulent flow. A detailed discussion of pressure drop and fans follows, with examples of application to electronics cabinet design. The radiation section deals with thermal management in space, for satellite and spacecraft applications. A detailed heat balance example follows.

The latter part of the course shows how to apply this information to the design and testing of electronic and other hardware. Advances in high density semiconductor integration have placed increased demands on thermal management and packaging in electronic hardware. Since conventional methods of electronics cooling may not meet the demands of new advanced designs, the instructor will discuss some advanced cooling techniques, some of which will set new industry standards in the 21st century. Topics covered include heat pipes, thermal modeling, power supply issues, ram air cooled electronics, PC board cooling alternatives, airflow balancing and a collection of useful hints and tips. A class project is included to provide supervised practice in using the course material.

The course is presented as a series of highly-interactive lecture/discussion sessions. Problems for individual and group solution are interspersed throughout the course to act as training aids and to evaluate class progress. Special-interest discussions are encouraged outside of the regular course sessions.

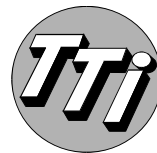
**CERTIFICATE PROGRAMS** This course is required for TTI's [Electronic Design Specialist \(EDS\)](#) and [Mechanical Design Specialist \(MDS\)](#) Certificate Programs, and may be used as an elective for any other [TTI Specialist Certificate Program](#).

**PREREQUISITES** There are no definite prerequisites. However, this course is aimed toward individuals involved in related technical fields.

**TEXT** Each student will receive a [course workbook](#) including most of the view-graphs used in the presentation.

**COURSE HOURS, CERTIFICATE, CEUs** Open courses meet seven hours per day. Upcoming presentation dates can be found on our current [open course schedule](#). Class hours/ days for on-site courses can vary from 14–35 hours over 2–5 days as requested by our clients. Upon successful course completion, each participant receives a certificate of completion and one Continuing Education Unit (CEU) for every ten class hours.

For [schedules](#), [general information](#) and [registration forms](#), see TTI's web site.



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# Cooling Methods for Electronics Design

## Course Outline No. 471

### Introduction

Effects of temperature on electronic components  
Junction temperature of an IC • Trends in thermal variables  
Emerging technologies • Definitions, temperature scales  
Basic thermodynamics, heat transfer mechanisms  
How to solve a thermal problem

### Heat Transfer by Conduction: Heat flows through a solid

Good thermal design • Series and parallel thermal resistance and conductance; Example  
Surface roughness and heat flow • Improving conduction: Metal foils, shims, thermal grease • Effect of contact pressure and area • Minimizing contact resistance • Example  
Thermal wedge clamp; Example • Bolt and washer conductance  
Metal core PC boards; materials; determining IC case to board core resistance • Thermal paths, thru-hole vias  
Amplifier internal heat sinking

### Thermal conductivity of:

Substrate materials, IC packaging materials, Adhesives  
Thermal spread angle; values for common materials; Example  
Diamond heat sinks

### Heat Transfer by Convection: Definitions, Nomenclature

Free or natural convection vs forced convection  
Heat transfer and film coefficients for air flow around different shapes • Heat transfer and fluids • Convection equation  
Effect of altitude • Cooling fins and heat sinks  
PC board spacing, power, and heat removal; Example  
Forced convection on PC boards; Example • Three methods of enhancing forced convection on PC boards • Turbulent and laminar forced convection inside shrouded fins; effect of fin tip gaps • Impingement cooling • Interleaved fins  
Pin Fins plus impingement flow  
Sample problems:

Natural convection • Heat sink • Laminar flow • Turbulent Flow

### Pressure Drop and Fans

Equation for circular sections • Fanning friction factor  
Cooling fan selection • Pressure vs. airflow • Air flow velocity charts • Testing at altitude  
Pressure drop measurement—tips • Flowmeter correction factor  
Cooling air parameters • Sample problem: electronics cabinet cooling • Pressure drop in electronics cabinets  
Typical enclosures, characteristics  
Fan selection example • Heat exchanger  
Cabinet ventilation area calculation for free convection  
Buoyancy pressure formulas • Flow resistance coefficient  
Sample problem • Commercial electronics cabinet cooling  
Fan and blower specifications

### Heat Transfer by Radiation

Heat exchange between different surfaces  
Radiation heat transfer equation • Shape or view factor curves  
Normal vs hemispherical emissivity • Thermal conductivity and insulation materials • Solar incidence angle  
Radiation heat transfer example • Spacecraft temperature factors  
Ground operations daily cycle: peak solar radiation vs. peak temperature • Radiant interchange factor  
Emissive power,  $\sigma T^4$  tables • Configuration factors for satellites  
Heat inputs for satellites: solar, earth, albedo  
Student problem: satellite surface heat, reducing internal heat  
Student problem: Thermal vacuum test setup • Thermal balance

### Sample Heat Balance Problems:

Calculating external surface temperature  
Calculating internal ambient temperature  
Transient heat balance example  
Example of developmental test data analysis

### Heat Pipes: Heat sinks and heat exchangers

Why a heat pipe works • Heat pipe sinks for electronic component cooling • Typical heat pipe components, fluid compatibility  
Field experience • Constant-conductance heat pipe  
Types of groove and wick configurations  
Diode heat pipe types:  
Liquid trap • Liquid blockage • Gas blockage  
Variable-conductance heat pipes (VCHPs) • Capillary pumped loop (CPL) • Comparison of VCHP and CPL performance  
Analysis: Heat pipe capacity • System pressure drop  
Thermodynamic consideration • Working fluids, compatibility  
Testing, applications, performance, references  
Experimental investigation of micro heat pipes in silicon wafers

### Thermal Modeling

Steady state mode (uses arithmetic nodes)  
Thermal model used to get boundary temp. for PC board model • Nodal grid overlaid on PC board  
Example of computer input data chart  
Transient mode (uses diffusion nodes) • Thermal modeling hints and tips • Thermal incidence angle • Radome thermal model

### Power Supply Issues: Calculating power supply requirements

Sample power supply problem  
Transistor mounting • Thermal circuit for transistors  
Fixing overheating problems:  
Two power transducers • Switching power supply—resistor heat sink • Ceramic dual in-line package  
Inductor and transformer • Diode module assembly

### Ram Air Cooled Electronics Example

Temperature vs. Altitude • Cooling airflow vs. Mach number  
Worst steady state conditions • Air Flow: heat balances  
Ambient cooling and bucket section  
The concept of sigma for pressure drop  
Maximum cooling air circuit pressure drop  
Altitude, pressure, and density • Pressure drop tests  
Alarm and cut-off switches

### PC Board Cooling Alternatives

Thermal design concepts for surface mount multilayer boards  
Cooling of electronics boards using internal fluid flows  
Underside Layout Configurations for Some Common ICs.

### Mechanical Engineer's Tool Kit

Off-the-shelf miniature couplers, pumps and fans  
Advanced flow control systems

### Miscellaneous

Practical suggestions • Thermal oven design procedure and example • Compromises relating to other disciplines  
Development temperature tests—tips • Thermal proposal outline  
Checklist for thermal modeling • Thermal considerations in automotive electronics • Dealing with management

### Air Flow Balancing: Single and multiple path boxes

Pressure drop tolerances • Flow balancing example  
Multiple boxes with a common plenum  
Cold plate interchangeability; Examples

### Summary • Final Review

Certificates for Successful Completion

# Cooling Techniques for Electronics Design

## Course No. 471

### ***Why is thermal analysis needed in the design of electronics packages?***

Quite simply, the cooler the parts operate, the more reliable they are. When equipment runs cooler, failure rates are lower and the mean time between failures is higher.

In today's economic environment, mechanical engineers often have to undertake the work of the specialized thermal engineer. A good understanding of thermal problems and how to solve them will help reduce redesign and its resulting schedule slip-page.

You will find Mr. Leatherman's approach to thermal analysis helpful for both system-level and component-level problems.

### ***Where has this course been held?***

This course has been presented to engineers and technicians at the following organizations:

Ball Aerospace, Boulder, CO

Lockheed Martin/British Aerospace, Manassas, VA

Boeing, Huntsville, AL

NASA-Glenn, Cleveland, OH

C-MAC Engineering, Kanata, Ontario

NASA-MSFC, Huntsville, AL

Dell Computer, Austin, TX

Nortel, Ottawa, Ontario

Hewlett Packard, Sacramento, CA

In addition, open courses have been held at Santa Barbara and Las Vegas for individuals from many organizations.

### ***Do the students feel the course is worthwhile?*** Here are some student comments on what they liked about 236

- Very good course. Knowledgeable instructor, excellent course material.
- Methodologies presented to solve any kind of thermal problems.
- The problem we had to solve and the methodical approach we were shown in finding the solution.
- Dick should be a professor. Best class I have ever taken.
- Dick Leatherman. He seemed to put a practical spin on the problems.
- The book provided will be extremely helpful with future projects.
- The explanations and real life situations that make the course nicer for learning.
- Good presentation of technical material, plus addition of practical knowledge.
- Very comprehensive. Materials were excellent.
- Practical knowledge presented by the instructor was very applicable.
- The content was very broad; from basics to modeling to design to test. And it included several practical suggestions/experience for each theory presented.
- Fantastic amount of material, practical applications and examples. Good balance of theory, practice, examples and war stories.
- Course instructor presented the material in a rational, comfortable manner. His presentation style and ability to relate to his students' interest level was much appreciated.
- Well presented, understandable; instructor not bogged-down in the details.
- It was really well focused on what we are doing as a business. Really well presented for engineers that are not thermal specialists.
- Course content, opportunity to interact and be taught by someone with such vast experience.
- Working through the thermal analysis of the class problem .
- Large volume of info about wide variety of situations and experiences.
- Practical solutions and applications brought by instructor with much experience.

### ***Remarks from student letters:***

- I would like to express my thanks for the delivery you gave on the thermal course. Nothing can replace personal experiences that relate to the formulas and principles. Bottom line, I noticed you gave it all you had. Also, the creativity that it needed was excellent. I totally enjoyed it. I heard the same comments from the troop that attended.
- Yesterday, I completed course # 236, at NASA Glenn Research Center (GRC). It was by far, the best training class I have ever taken at GRC. This type of training is typically only available in a course such as this. Mr. Leatherman covered a wide variety of practical heat transfer topics during the class. His years of experience and thorough knowledge of the subject were clearly reflected in his lectures.
- It's not often that we have training that is as on-target as this one and entertaining as well...my friend and I kept nudging each other with "he's been there, he's been there."