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Experimental Characterisation of Electronic Components and System Thermal Performance

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Introduction

To satisfy consumer demands for more compact and sophisticated electronic devices, advances of semiconductor technology have achieved increased Integrated Circuit (IC) functionality and miniaturisation. However, the continuous increase of both switching speed and transistor density, still described by Moore's law, have inadvertently resulted in rising die heat fluxes, which, if not efficiently removed from the device, may impact on product performance and reliability. While no generic relationship exists to relate component and Printed Circuit Board (PCB) temperature with reliability, it has been shown that die circuit performance can be highly sensitive to operating temperature, and therefore temperature must be controlled.

This need, combined with the demand for more reliable electronic systems, has heightened the requirement for accurate characterisation of product thermal performance. Although thermal design practices have evolved to a high reliance on virtual prototyping using numerical predictive techniques, relying solely on numerical predictions without experimental analysis still remains an unreliable design strategy. An efficient thermal design process therefore requires a balanced combination of experimental and numerical efforts, whereby experimentation is used to both provide critical physical boundary conditions for numerical analysis and verify the numerical models. Ultimately, experimental characterisation is necessary to assess the effectiveness of the cooling design both at system level and locally at critical component locations, from which component reliability, hence product life, can be estimated.

This course covers the fundamentals of thermofluid measurements to characterise electronics thermal performance, from component to system level. The principles and application of experimental techniques to measure the critical physical parameters involved, such as temperature, fluid flow and heat transfer, are reviewed. Specific methods for characterising important system elements, such as IC packages, populated boards, racks, heat sinks, fans, and grilles/vents are outlined. Electronics thermal characterisation standards, and both standard and non-standard characterisation environments are reviewed. Practical case studies dealing with the thermal characterisation of telecommunication products are presented.

Course objectives

This course provides experimental strategies and methodologies to characterise electronic system thermal performance, from component to system level. The application of these techniques will permit the thermofluid phenomena in a given application to be understood, will guide the thermal design process and ultimately permit product thermal performance to be qualified.

Who should attend?

The course will benefit engineers, managers and scientists involved in the thermal management, thermo-mechanical issues or reliability of electronic systems. It is aimed at participants with varying expertise levels in thermal management, from novice to advanced.

Course outline

1. The need for experimentation

- Characterisation of electronics thermal performance for reliability
- Supporting analysis for numerical modelling
  - Physical boundary conditions
  - Numerical model validation
- Physical measurement parameters
  - Primary: temperature, velocity, flow rate, pressure, heat transfer
  - Secondary: humidity, acoustic noise, material thermal conductivity
- Uncertainty analysis
  - Estimating measurement uncertainty
  - Mathematical analysis
  - Single sample uncertainty analysis
  - Reporting uncertainties

2. Measurement Techniques

- Temperature measurement
  - Thermocouples
  - Thermistors
  - Resistance thermometry
  - Radiation thermometry
  - Liquid crystal thermometry
  - Interferometry
- Velocity measurement
  - Pressure-based techniques
  - Hot Wire Anemometry (HWA)
  - Laser Doppler Anemometry (LDA)
  - Particle Image Velocimetry (PIV)
- Flow rate measurement
  - Rotameter
  - Orifice plate
  - Laminar flow element
  - Vortex eddy flow meter
  - Thermal mass flow meter
- Pressure measurement
  - Static and dynamic pressure measurement
  - Differential pressure methods (manometers)
  - Pitot-static probe design
  - Pressure tap design
- Heat transfer
  - Heat flux gauges (thermopiles)
- Humidity
  - Gravimetric procedure
  - Dry and wet bulb thermometer
  - Electrical transducer
- Acoustic noise emission (air movement)
  - Sound pressure level
  - Sound power level
- Material thermal conductivity and diffusivity measurement
  - Long bar method
  - Three-omega method
  - Flash method

3. Thermal characterisation environments

- Wind tunnel design
  - Standard design: SEMI G38-0996, EIA/JEDEC JESD51-6
  - Customised design: design principles, aerodynamic design, flow management elements
- Fan characterisation unit
  - International standards: BS 848, ANSI/AMCA 210-85, ANSI/ASCHRAE 51-1985
- Enclosures
  - Temperature-controlled ovens, still-air enclosures

4. Component thermal characterisation

- International standards for junction-to reference thermal resistance measurement
  - EIA/JEDEC, SEMI, MIL, DELPHI
- Component junction temperature measurement
  - Direct methods: electrical techniques - thermal test chips, switching method
  - Indirect methods: infrared thermography, liquid crystals
  - Figures-of-merit calculation: junction-to-reference thermal resistance (applicability/limitations)

5. Unit level characterisation

- Heat sink thermal characterisation
- Fan performance testing
- Grilles, vents: pressure loss coefficient measurement
- Flow visualisation
  - Airflow visualisation
    - Smoke entrainment: smoke-wire, smoke-tube methods
  - Liquid flow visualisation
    - Dimensional analysis and similitude
    - Dye entrainment (ink streaks)
  - Surface flow visualisation
    - Paint film techniques: ink-dot and powder-based methods
    - Mass transfer: sublimation- and evaporation-based methods
    - Tuft probes

6. System thermofluid characterisation

- Prototype mock-up design
- Thermal characterisation procedure
- System flow impedance measurement

7. Electronics thermal characterisation case studies

- Multi-component printed circuit board
- Mobile phone
- Telecommunication cabinet

8. Summary

Instructor background

Dr. Peter Rodgers is director of Electronics Thermal Management Ltd., a research and consulting firm specialised in electronics cooling. He holds a Ph.D. degree in mechanical engineering from the University of Limerick, Ireland and has been involved in electronics thermal management for thirteen years. Dr. Rodgers was formerly with the Nokia Research Center, Finland, where he consulted on electronics thermal management within the corporation, and lead a research programme on benchmarking the predictive accuracy of CFD codes dedicated to the thermal analysis of electronic equipment. For publications associated with this work, he was awarded the 1999 Harvey Rosten Award for Excellence. He has an extensive experimental background in electronics cooling, which includes the development of advanced experimental techniques to characterise thermofluid phenomena. In his previous positions, he contributed to the development of state-of-the art thermofluids laboratories both at the University of Limerick, Ireland and the Nokia Research Center. Dr. Rodgers is a member of the EuroSIME, SEMI-THERM and THERMINIC conference programme committees, and has been an invited lecturer, keynote speaker, and panelist to discussions on simulation issues in electronics thermal management at international conferences. He has authored or co-authored over thirty refereed conference and journal publications.