Heat Sink Design and Analysis for Microelectronic Equipment

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Introduction

Heat sinks are the most common, cost-effective hardware employed for the thermal management of microelectronic equipment, with applications spanning from microchannel cooling to component- and circuit board thermal control. Heat sinks function by extending the surface area of heat dissipating surfaces through the use of fins. Their design and analysis is one of the most extensive research areas in electronics cooling.

Ever-rising electronic component power dissipation, combined with both the demand for more compact and lighter equipment, and manufacturing constraints, place increasing challenges on the optimisation of heat sink thermal performance today. This is compounded by shortening product design cycle times, which heighten the requirement for innovative thermal design methods enabling accurate heat sink designs to be generated and quickly assessed. An efficient thermal design process involves the use of analytical and semi-empirical calculations to establish an initial heat sink design, which is refined by numerical analysis to account for the impact of the application environment on thermal performance. The effectiveness of the heat sink design ultimately needs to be verified by experimentation.

The course provides an overview of the state-of-the-art and general trends in heat sink design. Apart from convective and radiative heat transfer optimisation, the course addresses key issues in advancing heat sink thermal performance, including contact thermal resistance, integration of heat spreading technologies and entropy minimisation. Practical case studies dealing with heat sink design optimisation are presented.

Course objectives

This course provides a comprehensive treatment of the design and analysis of heat sinks. It combines theoretical and practical information to successfully design or select cost-effective heat sinks for microelectronic equipment. The attendee will gain an appreciation of both the fundamental performance limits of heat sinks, and current state-of-the-art in heat sink technology.

Who should attend?

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

Course outline

1. Introduction

- Fundamentals of heat transfer
  - Conductive, convective and radiative heat transfer processes
- Thermal analysis and design process
  - Application of analytical, experimental and numerical analyses
  - Overview of the latest commercial thermal design software packages
- Heat dissipation trends in electronic systems
  - Heat transfer chain
  - Limits of air-cooling: passive versus active

2. Evolution of Heat Sink Design and Analysis

- Analytical analysis
  - Fin efficiency
  - Radiative heat transfer models
- Experimentation
  - Derivation of correlations for the convective heat transfer coefficient as a function of heat sink geometry and convective environment
  - Friction factor correlations
- Numerical analysis
  - Investigation of thermofluid phenomenaUse of Computational Fluid Dynamics (CFD) methods to predict heat sink performance in application environment
- Heat sink design optimisation
  - Fin geometry: fin spacing and thickness as a function of heat sink rectilinear volume and given convective environment
  - Manufacturability: fin aspect ratio, production cost
  - Entropy minimisation methodology: energy and material consumed in the fabrication and operation of heat sink
- Key observations from past work

3. Heat Sink Technologies

- Types of heat sink designs
  - Straight, staggered, pin and amorphous fin designs
  - Porous designs: foams, weave-screen laminates
  - Passive and active heat sinks
  - Forced-air cooling: side entrance inlet flow versus impingement flow
- High-performance heat sink designs
  - Augmented, bonded, folded, forged and cast designs
- Survey of future trends on heat sink performance
  - Limits of air-cooling
  - Manufacturability constraints

4. Current Design and Analysis Methods for Air-Cooled Heat Sinks

- Heat sink characterisation
  - Vendor characterisation methods of heat sink performance and their limitations
  - Heat sink selection
    - How to select a heat sink from manufacturer catalogues
- Customised heat sink design
  - Environmental and physical conditions
  - Initial feasibility study
  - Preliminary heat sink design
  - Heat sink optimisation
    - Convective and radiative performance
    - Conductive performance
      - Fin efficiency
      - Heat spreading: heat pipes, vapour chambers, improved thermal conductivity materials
    - Design for manufacturability
    - Least-energy optimisation
- Heat sink attachment
  - Contact thermal resistance and interface materials
    - Properties of interface materials
    - Types of interface materials
- Airflow management
  - Fan performance
    - Fan/blower/impeller selection
    - Assessment of vendor specified fan curve performance
    - Change in fan curve characteristics due to application environment
  - Effect of grille and filter open area on system impedance
- Compact modelling of heat sink thermofluid characteristics for system-level numerical analysis

5. Case Studies: Heat Sink Design and Application

- Microprocessor cooling
- Telecommunication cabinet unit cooling

6. Summary

Instructor background

Dr. Peter Rodgers is an Assistant Research Professor at the University of Maryland, College Park, where he supports the thermofluid research of the CALCE Electronic Products and Systems Center. He holds a Ph.D. degree in mechanical engineering from the University of Limerick, Ireland and has extensive experience of electronic equipment thermal design and characterisation. He was formerly with Electronics Thermal Management Ltd., Ireland, and the Nokia Research Center, Finland, where he consulted on electronics cooling. He is recipient of the 1999 Harvey Rosten Award for Excellence, awarded for his publications on the application of CFD analysis to electronics thermal design. Other research interests include the design of high-performance heat sinks, and the development of advanced experimental techniques to characterise thermofluid phenomena in electronic systems. He is a participant in the JSME Project, "Design and Manufacture of High-Performance Heat Sinks for Microelectronic Equipment". He is a member of several international conference program committees and has authored or co-authored approximately forty conference and journal publications on a broad range of topics related to electronics cooling. He has been an invited lecturer, track- and session chair and panelist at international conferences.

Dr. Valérie Eveloy is with Electronics Thermal Management Ltd., a research and consulting firm specialized in electronics cooling. She has been involved in electronics cooling for nine years, and was previously a Research Engineer with the Nokia Research Center, Finland, where her activities focused on the thermal management of telecommunication products and the selection of RF IC packaging solutions. She has authored or co-authored over twenty five conference and journal publications, holds an M.Sc. degree in physical engineering from the National Institute of Applied Science (INSA), France, and a Ph.D. degree in mechanical engineering from Dublin City University, Ireland.