Client Platform
Engineering – PCCG

Laptop Cooling Basics

Ketan R. Shah
Principal Engineer
Intel Corporation
Q1, 2011

Laptop Cooling Basics - Agenda

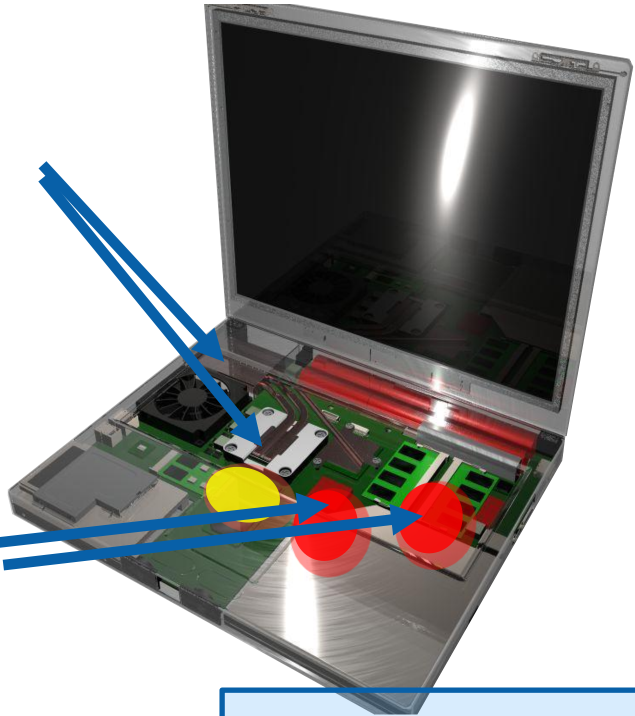
- Laptop Cooling Challenges
- Laptop System Cooling
  - Heat transfer modes
  - System & motherboard layout – Airflow & venting
  - System analysis & design - Component interactions
- CPU Cooling
  - Heat transfer modes
  - Heatpipe basics
  - Heatpipe heat exchanger
- Summary

Laptop Cooling is a System Level Problem.

Laptop Cooling Challenge – I: Thermodynamic Limit: What goes in must come out!

CPU power load heats attach and heat exchanger

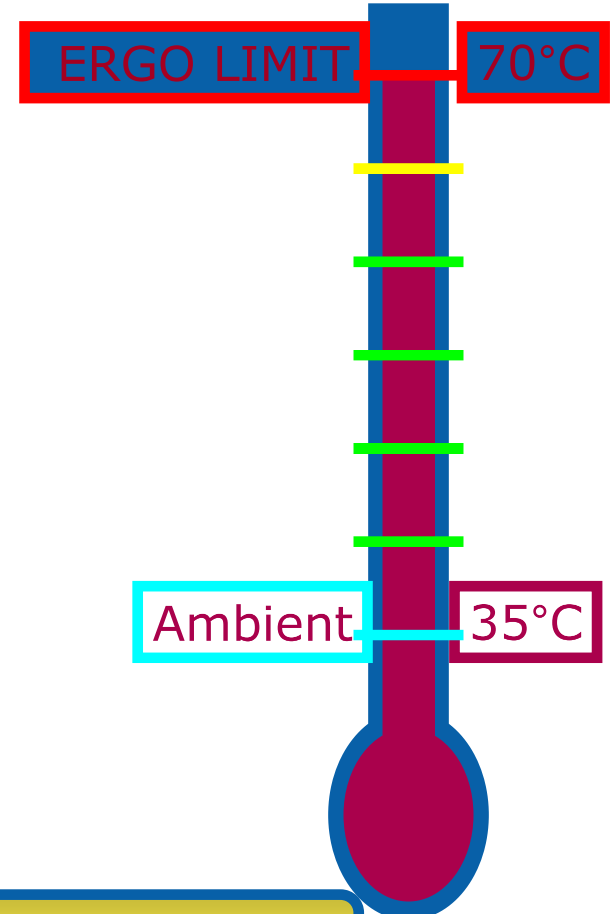
Chipset Memory, Wireless, etc., also contribute to exhaust temperature



$$\text{Exhaust T} \sim \frac{\text{Heat Removed}}{\text{Fan Flow Rate}}$$

3 cfm fan flow ⇒ 60W dissipation

Exhaust Temperature



System power envelope is fixed by fan airflow capability!

Laptop Cooling Challenge - II: Skin Temperature

Problem #1
Each customer picks their own skin temperature limits

Problem #2
Most current limits stretch or exceed the human ergonomic comfort level

Jury Study!

Notebook Skin Temperature Limits (o C)
40-50 deg C (Plastics are 5-10C higher)

Problem #3
Material type, thickness, and surface finish all matter ('temperature' is NOT ENOUGH)

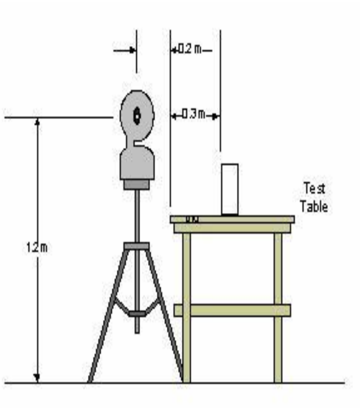
Problem #4
Usage matters too → notebook does not equal tablet or handheld

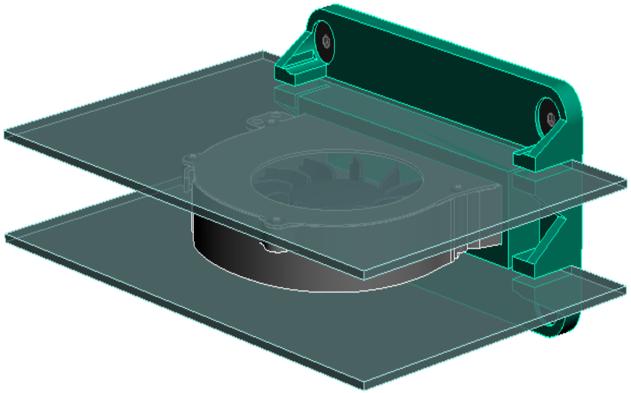
System power capability is constrained by skin temperature needs.

Laptop Cooling Challenge: III: Acoustics

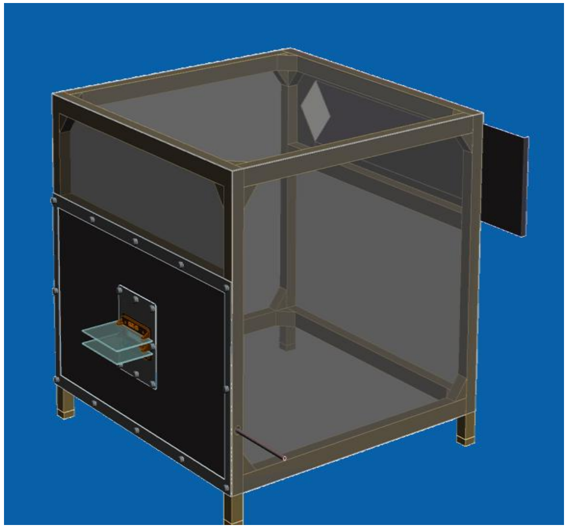
- Manufacturers spec fan noise:
  - Bare fan → different from in-system!
  - Free flow → different from in-system!

- The notebook-relevant test methodology





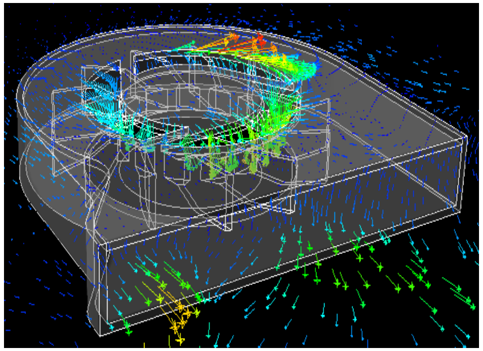
Simulating Notebook Geometry



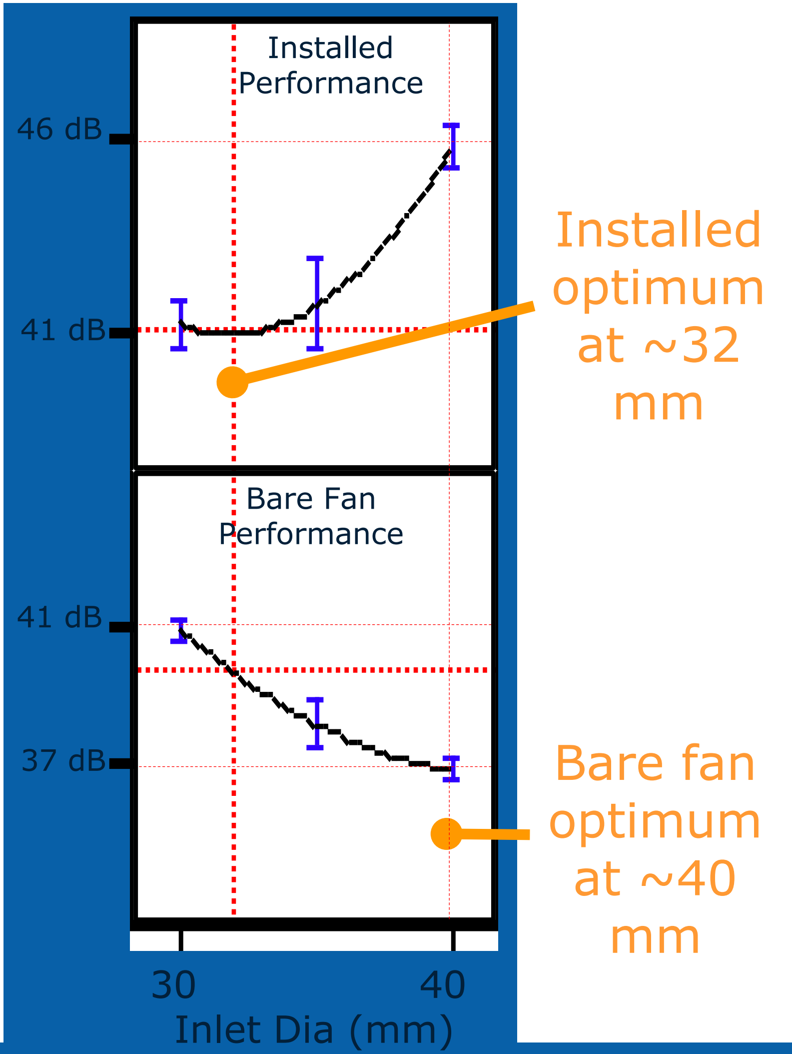
Plenum Tests Fans Under Load

Acoustics - Optimization

- Combining Intel metrology with DOE analysis
- Installed fan acoustic optimization
  - 5 dB improvement shown!
- CFD analysis of fan aero-acoustics

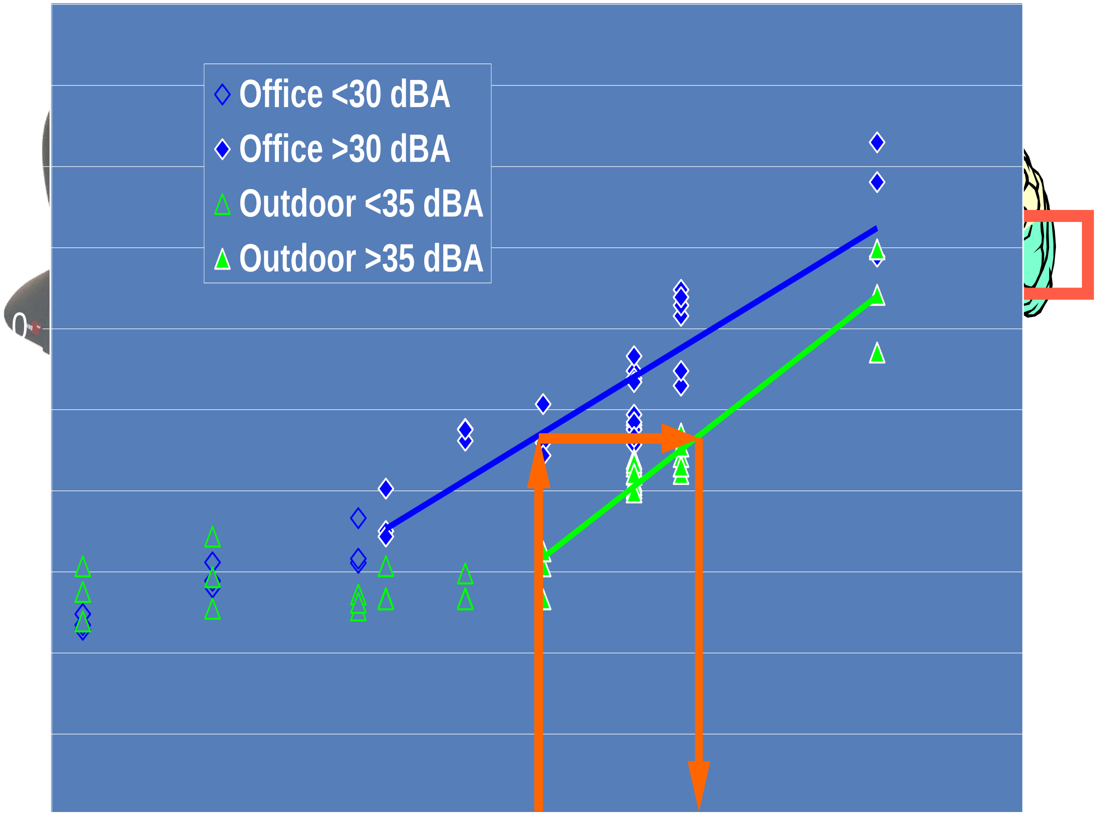


Measured Fan Noise



Acoustics –Jury Study

- Binaural recordings made of notebook noise
  - 22 Systems, 14 manufacturers
- Jurors
  - Geography: USA, Sweden, Japan
- An Annoyance Model was developed.
  - Includes sound pressure (loudness) AND sound quality



System acoustics need to be <35-40 dBA.

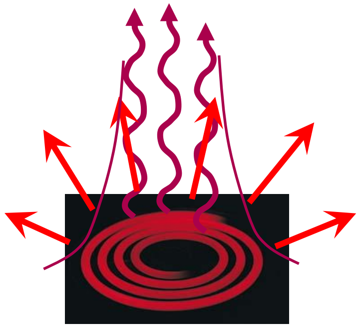
Laptop Cooling Challenges - Summary

- Thermodynamic limit: Exhaust temperature
- Skin Temperature
- Acoustics
- Maximum system ambient temperature (@ inlet): 35°C

<u>In addition to the</u>

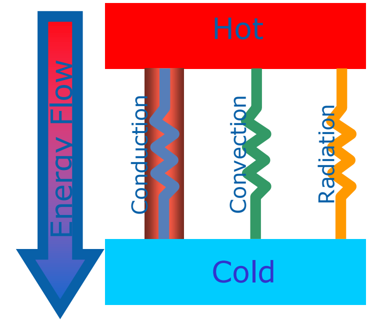
- Component temperatures
  - CPU, GMCH, memory, COMMs, VRs, etc., etc.

Heat Transfer 101 – 3 Modes of Heat Transfer



Hot Stove Element

- Conduction felt (!) if you touch it → $\Theta_{cond} \sim L/k*A$
- Convection felt in hot rising plume → $\Theta_{conv} \sim 1/h*A$
- Radiation felt from all directions → $\Theta_{rad} \sim 1/\varepsilon T^3*A$



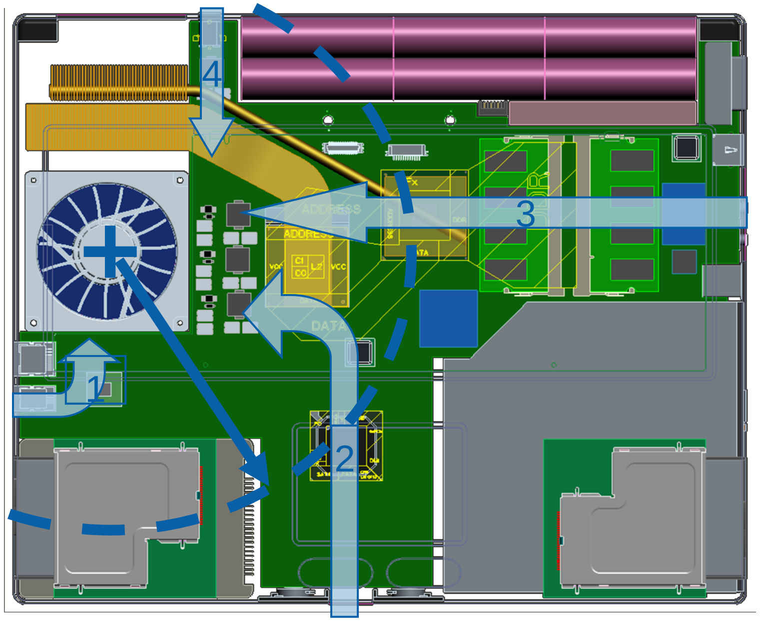
Increasing Thermal Resistance Magnitude →

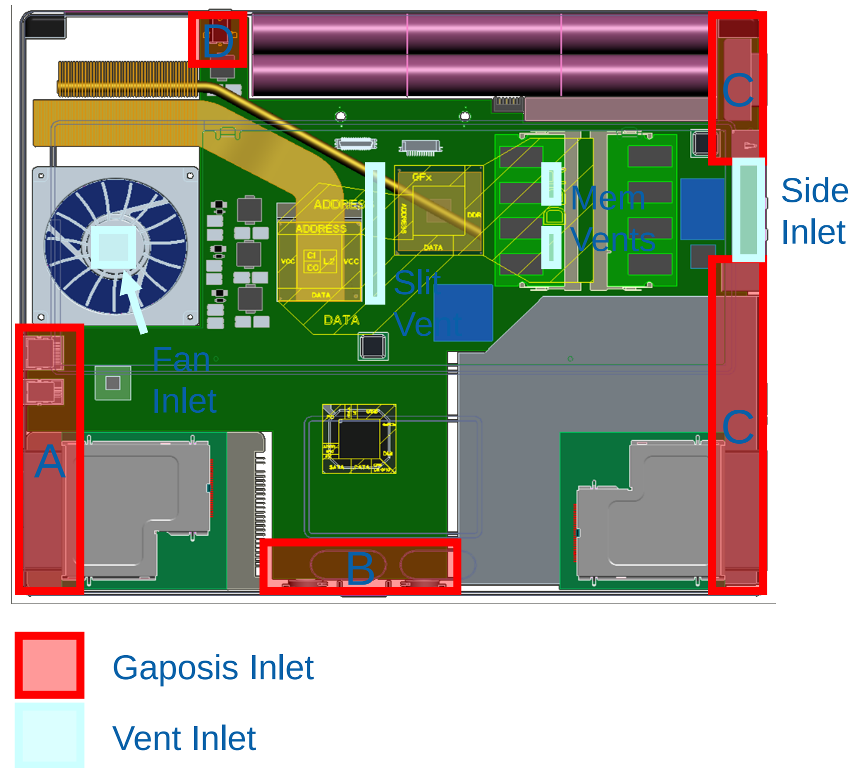
Nominal Units °C/W

10^0 10^1 10^2 10^3 10^4 10^5

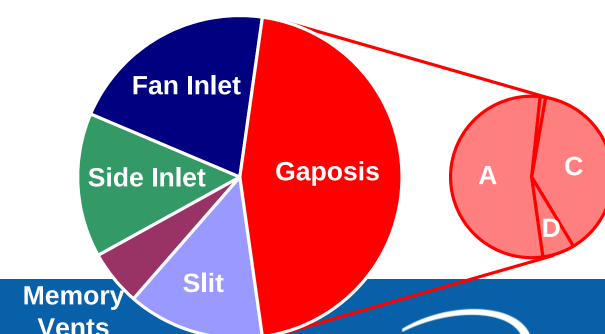
- Conduction: Heat Pipe, Metals, Plastics
- Convection: High Speed, Low Speed
- Radiation: Very High Temp, High Temp, Ambient

Convection – Air Flow and Venting





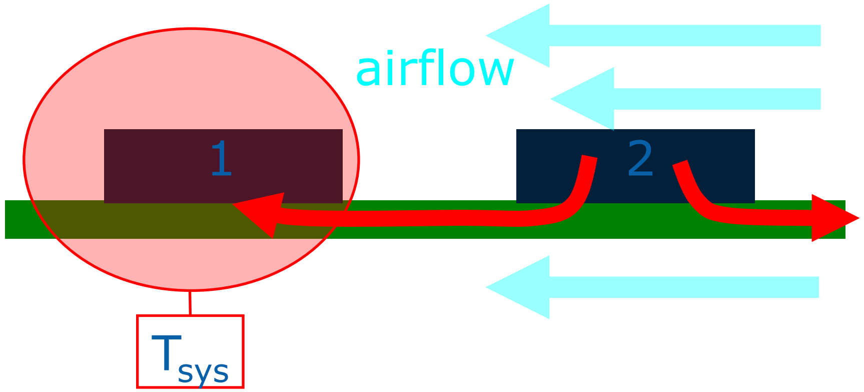
- All roads lead to Rome (the fan)
- Good to distribute flow paths azimuthally



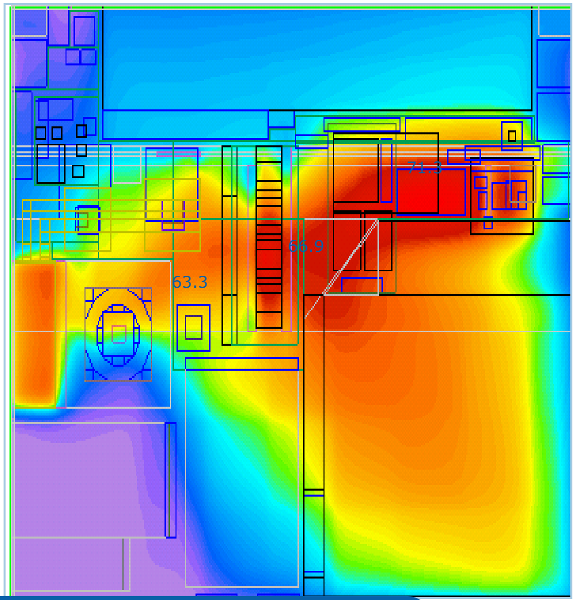
Component Interactions

- Many components at Tj_max simultaneously
  - Component to component influence:
    - Conduction
    - Convection
  - Each component has 'local ambient':

    $T_{local} = T_{ambient} + T_{sys}$



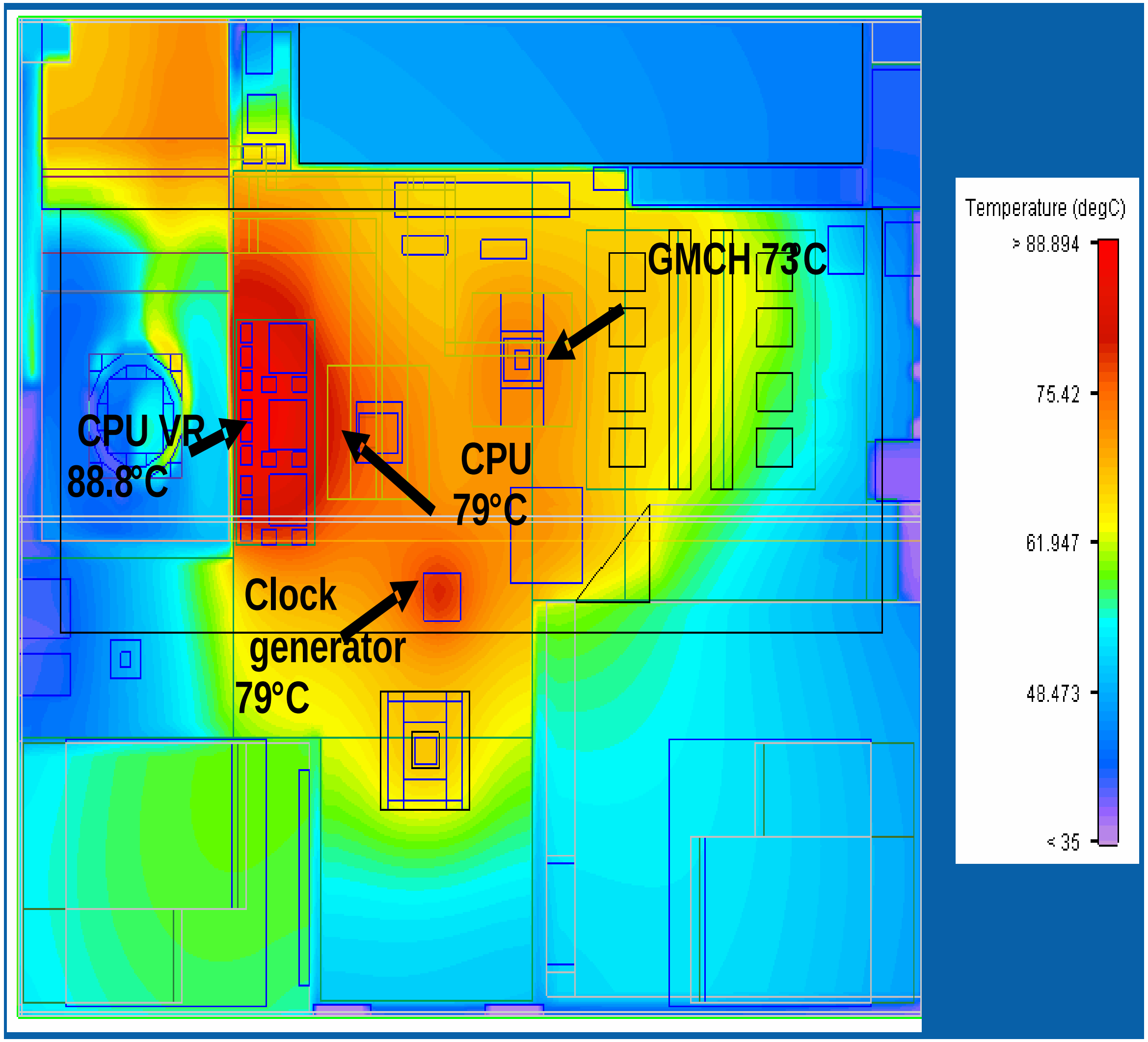
- Determining T_{sys} requires detailed platform level thermal simulations
  - Accuracy challenges
  - Significant benchmarking/calibration required
  - Intel presents seminars on modeling methodologies to OEMs/ODMs



$$Power_{component} = (T_j - T_{local})/\Theta$$

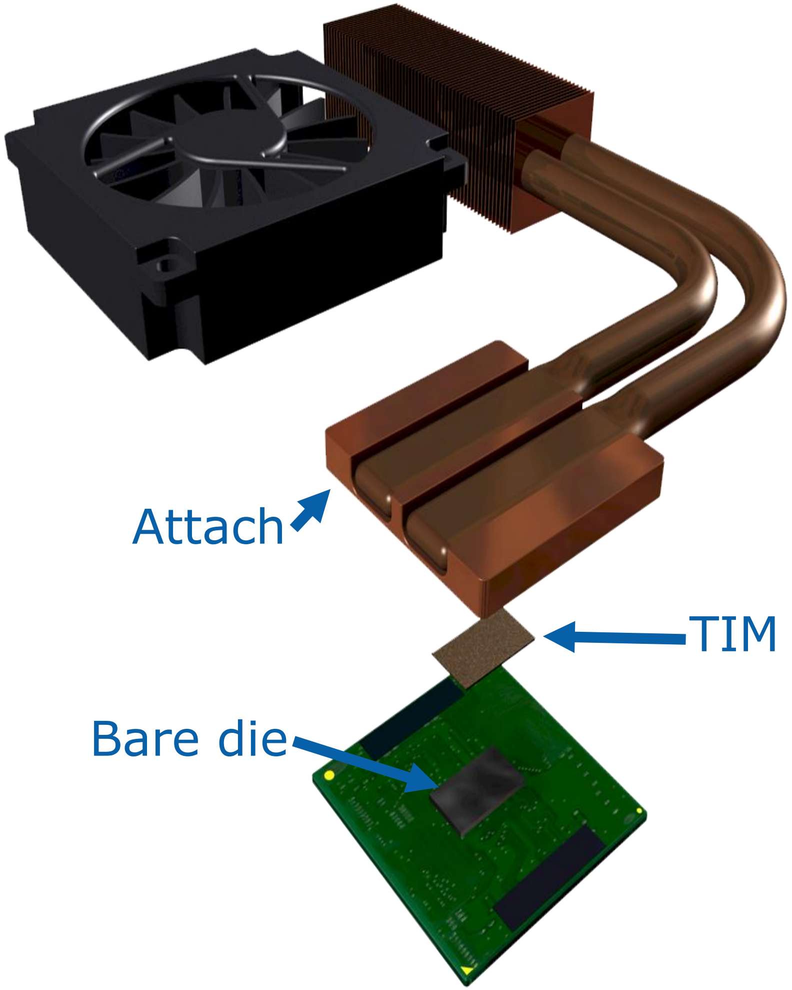
Conduction – The Motherboard

- Motherboard is warm around all key components
  - provides bottom side cooling
- Proximity aggravates thermal problem (T_{sys})
  - HDI
  - Smaller FFs



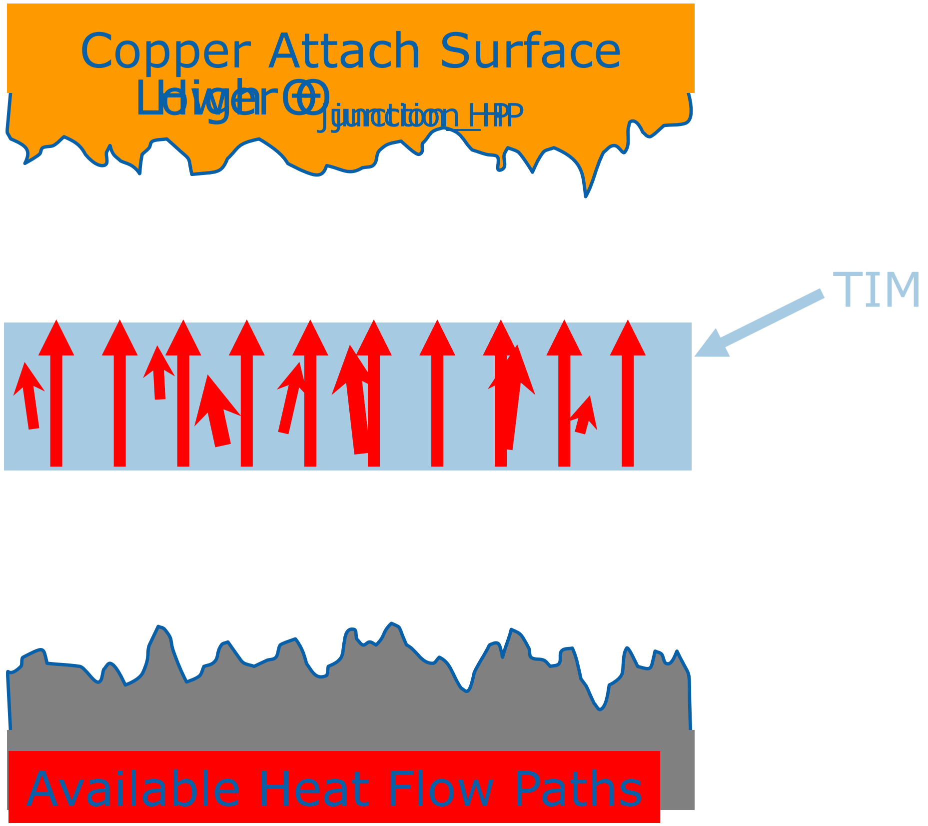
Getting Heat Out of CPU

- Bare die thermal attach
  - Density Factor (power map) critical
- Thermal Interface Material (TIM)
- Solid copper attach block



Thermal Interface Materials (TIMs)

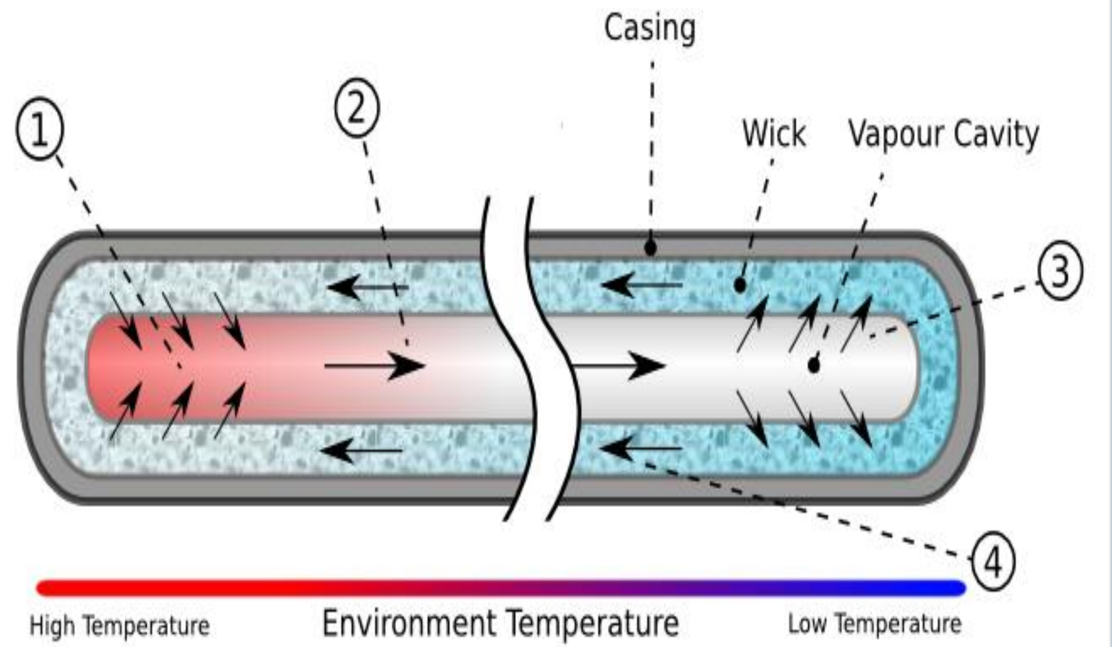
- Fills air gaps
- Improves thermal contact
- Various materials used:
  - Compliant
  - High thermal conductivity
- Key issues:
  - Pressure required
  - Long term reliability



Microscopic view

Heat Pipes

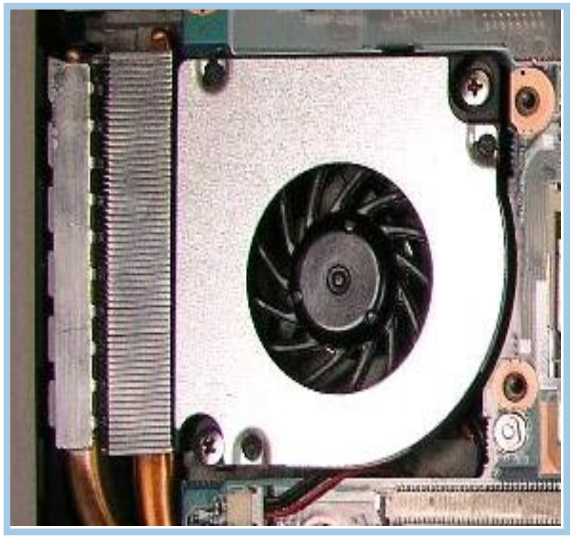
- Your notebook uses liquid cooling
- High 'effective' thermal conductivity along length
- Key issues:
  - Max heat throughput (dry out)
  - Minimum thickness



Heat pipe thermal cycle

1) Working fluid evaporates to vapour absorbing thermal energy.
2) Vapour migrates along cavity to lower temperature end.
3) Vapour condenses back to fluid and is absorbed by the wick, releasing thermal energy
4) Working fluid flows back to higher temperature end.

Fan and Heat Exchanger



FANS

- Basic centrifugal blower used in most systems

Heat Exchangers

- Nearly all systems use uniformly spaced vertical copper fins

Acoustics and Air Flow are king!

•*Fan air flow defines system power envelope*

Laptop Cooling Basics - Summary

- Summary
  - Laptop system cooling is designed to work with constraints of component temperatures, exhaust and skin temperatures, as well as acoustics.
  - CPU cooling relies on multiple technologies of TIM, heatpipe, centrifugal blower, and heat exchanger.

Laptop Cooling Requires an Integrated Approach.