The Thermal Design and Management of NB

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Agenda

- NB Configuration
- Specification
- Thermal Resistance
- Thermal Design Power
- Thermal Validation & Analysis
- Thermal Management
- Summary

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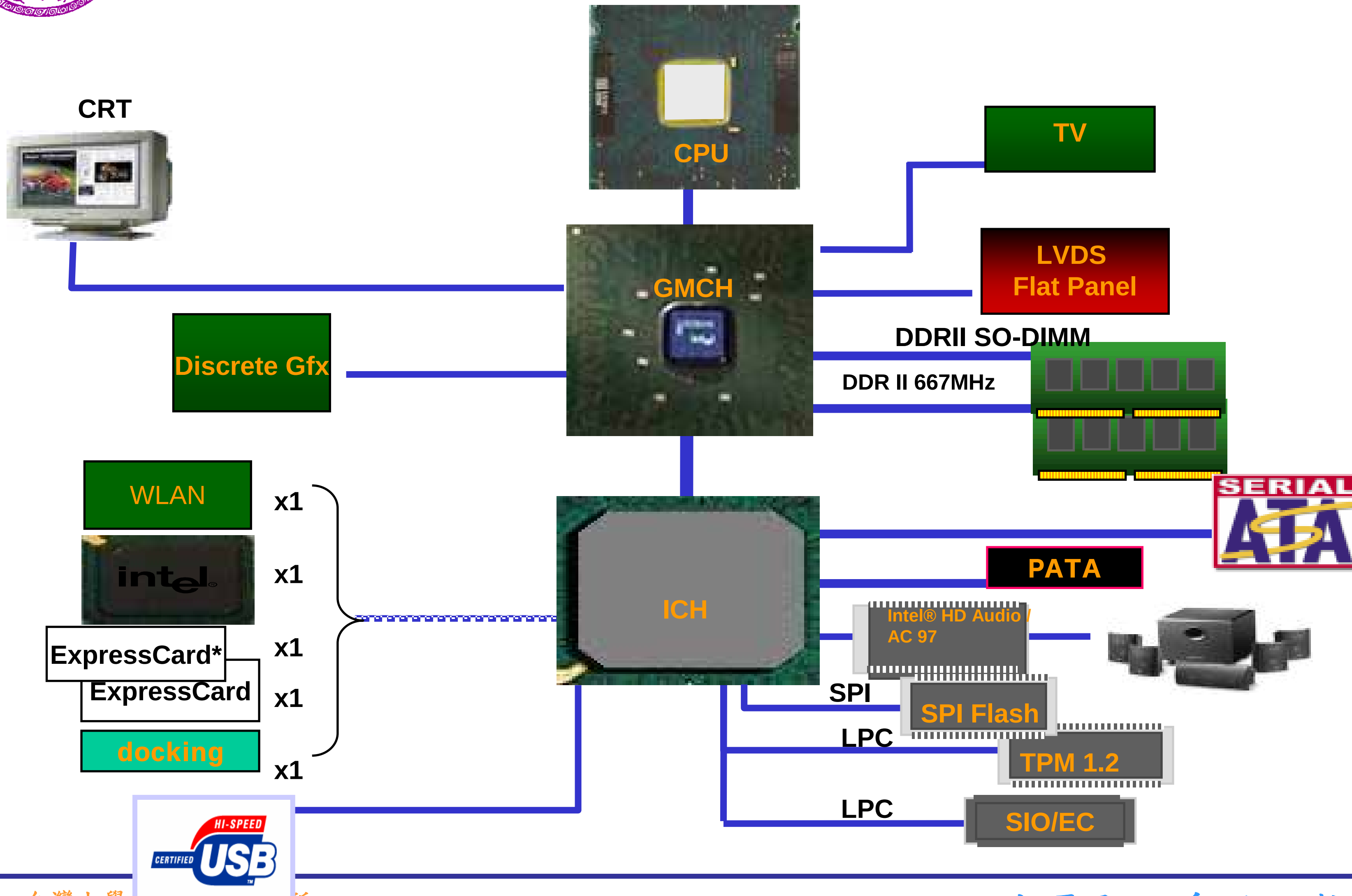
NB Configuration



System Configuration (example)

OEM	SONY
Model	VAIO VGN-S90S
CPU	Pentium M 745 (1.8GHz Dothan)
Chipset	Intel 855PM
Video	ATI MOBILITY RADEON9700 64MB
Wireless LAN	Intel PRO/Wireless 2200BG
Memory	768(256+512)MB (PC2700)
HDD	40GB, 2.5in.
OS	Windows XP Home Edition SP1
Dimensions(x,y,z)	313 x 225 x (31.0~32.0) mm
Monitor	13.3 in TFT (WXGA)
Weight	1915.5 g

Top

Bottom

Battery

W-LAN Module

Memory

SONY VAIO type-S VGN-S90S

System Configuration (example)

Front　　Back

Left　　Right

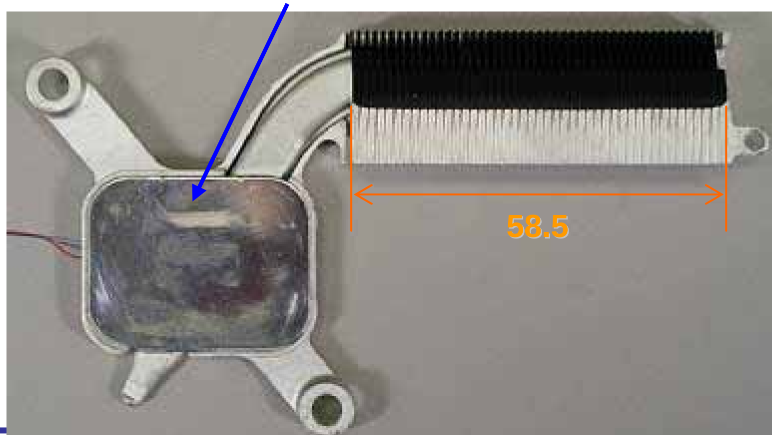
System Configuration (example)

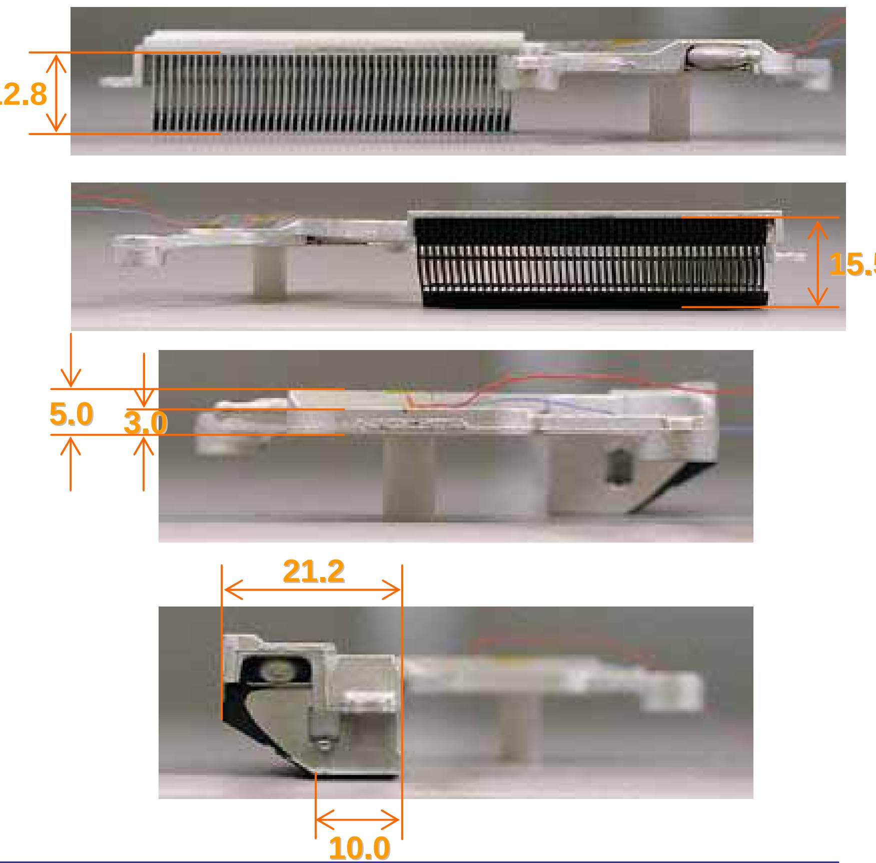
TIM (On CPU) : THERMAGON T-pcm 905c (PCM)

Heat pipe for CPU : 6mm x 3mm

Fin			
	Piece	:	45 pieces
	Thickness	:	0.3mm
	Gap	:	1.0mm

Copper Heat Block : 36.0 x 28.0 x 1.0 mm





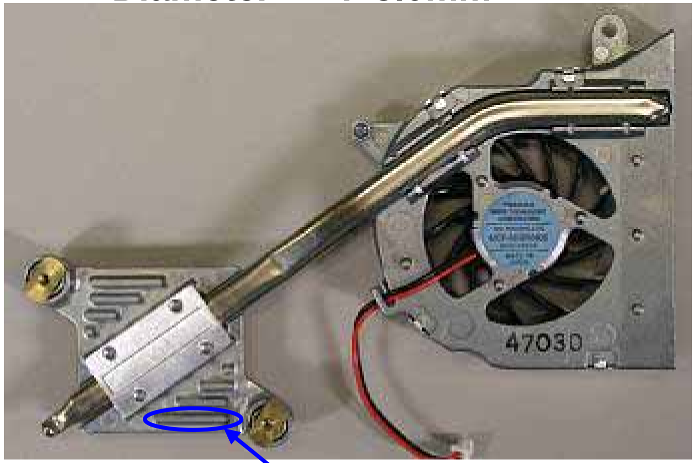
Units : mm

System Configuration (example)

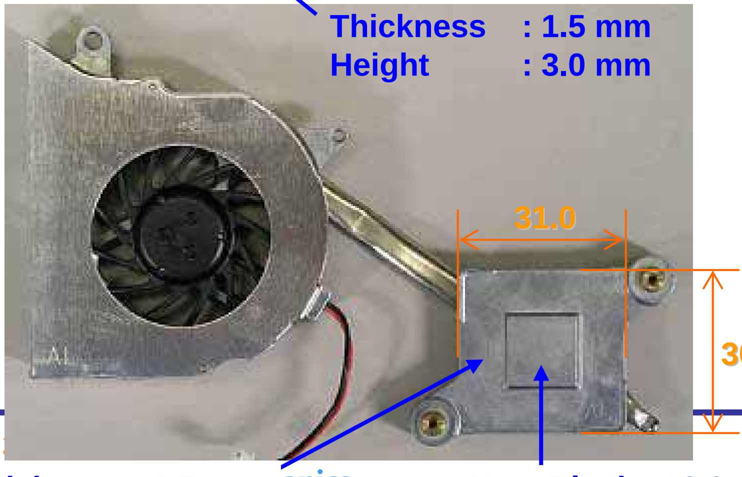
TIM (On GFX) : THERMAGON
T-pcm 905c (Phase change)

Heat pipe for GFX
Diameter : 5.0mm

CPU Fan TOSHIBA HOME TECHNOLOGY
MCF-509PAM05
Size : 54.2x52.0x12.5mm
Input power : DC 5 V, 0.25A
Weight : 42.2g (with HS)

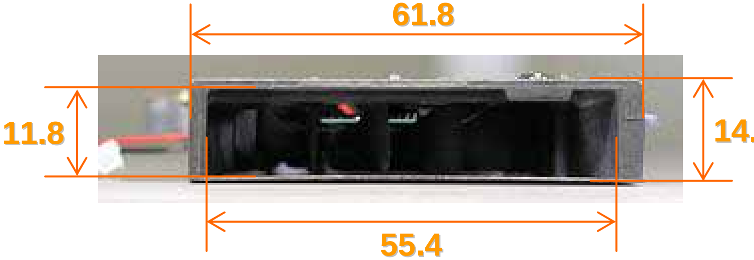


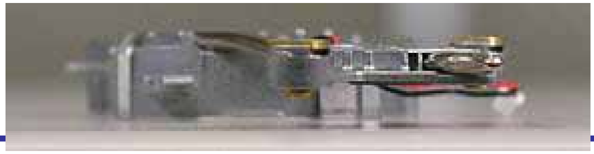
Thickness : 1.5 mm
Height : 3.0 mm



Thickness : 1.5 mm

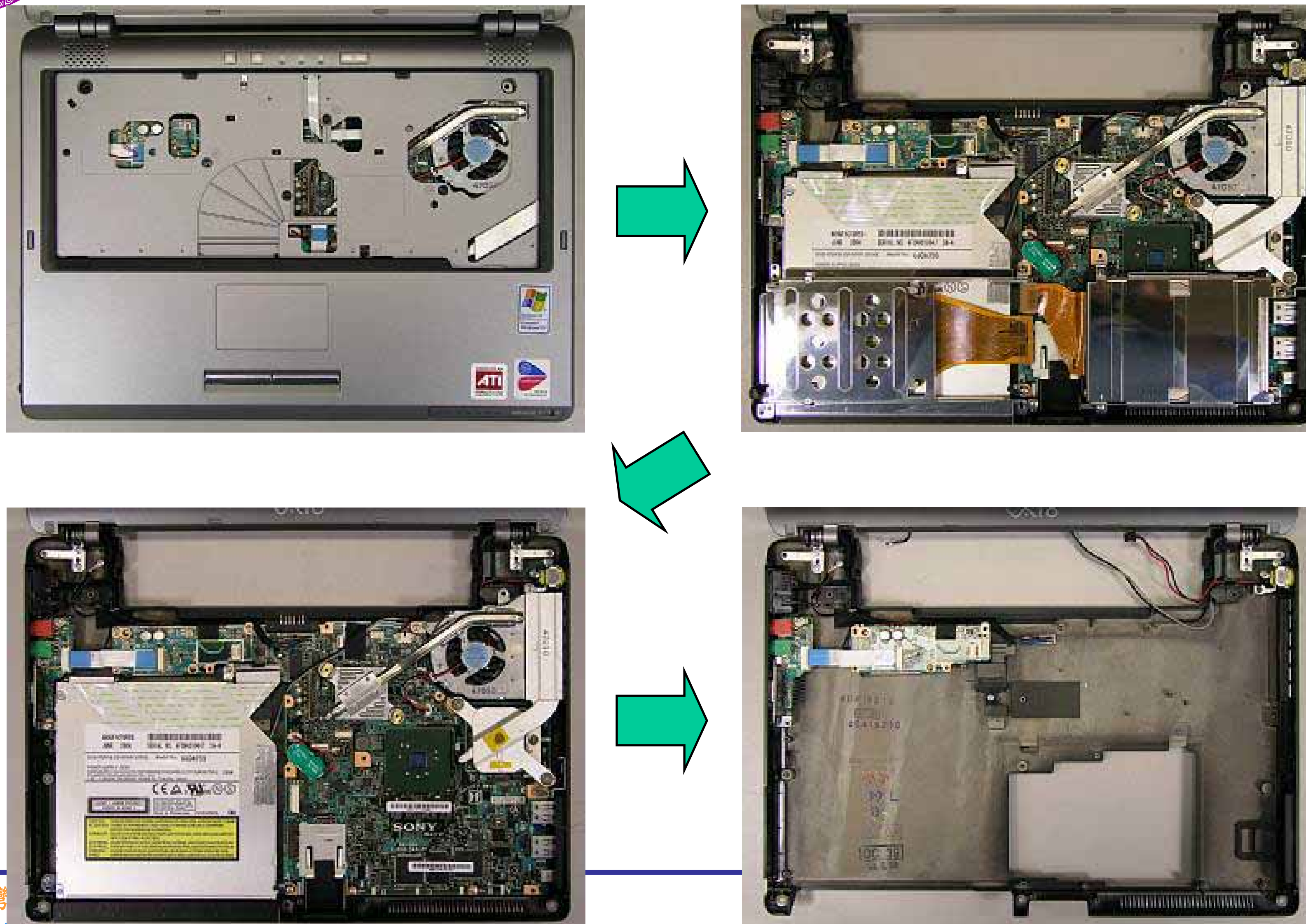
Heat Block : 13.0 x 13.0 x 0.75 mm





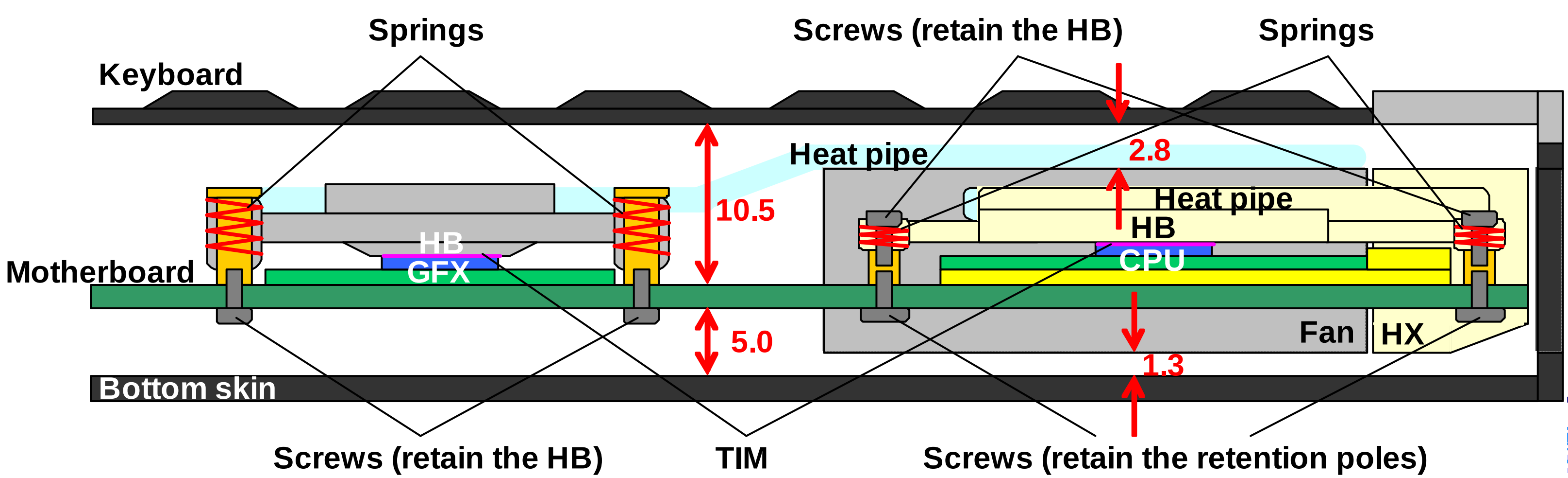
Units : mm

System Configuration (example)

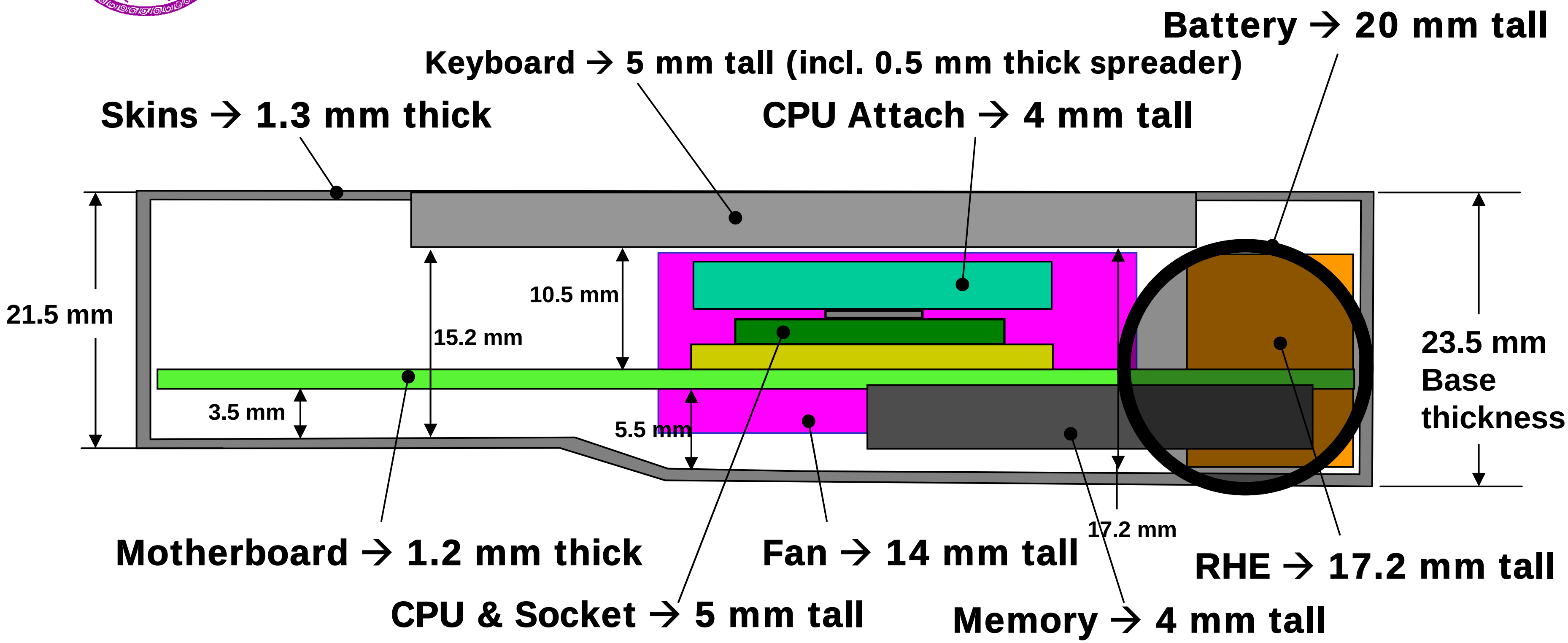


Mechanical Configuration

- Thermal solution for CPU is retained by 2 screws with embedded spring
  - Retention torque: 7.5cNm and 11.0cNm
  - Screws do not reach the system chassis
- Thermal solution for GFX is retained by 2 screws with embedded spring
  - Retention torque: 10.0cNm
  - Screws do not reach the system chassis
- Heat exchanger is retained by one screw
  - This screw reaches the system chassis and is concerned in hot spot of bottom skin



Wedge Design Stackup (example)



- Screen thickness ~7 mm
- Total system 28.5-30.5 mm (1.1-1.2")

CPU Access

Samsang X30

Clevo E260

Dell P2

Wistron D2U

ECS 556

Samsung X30

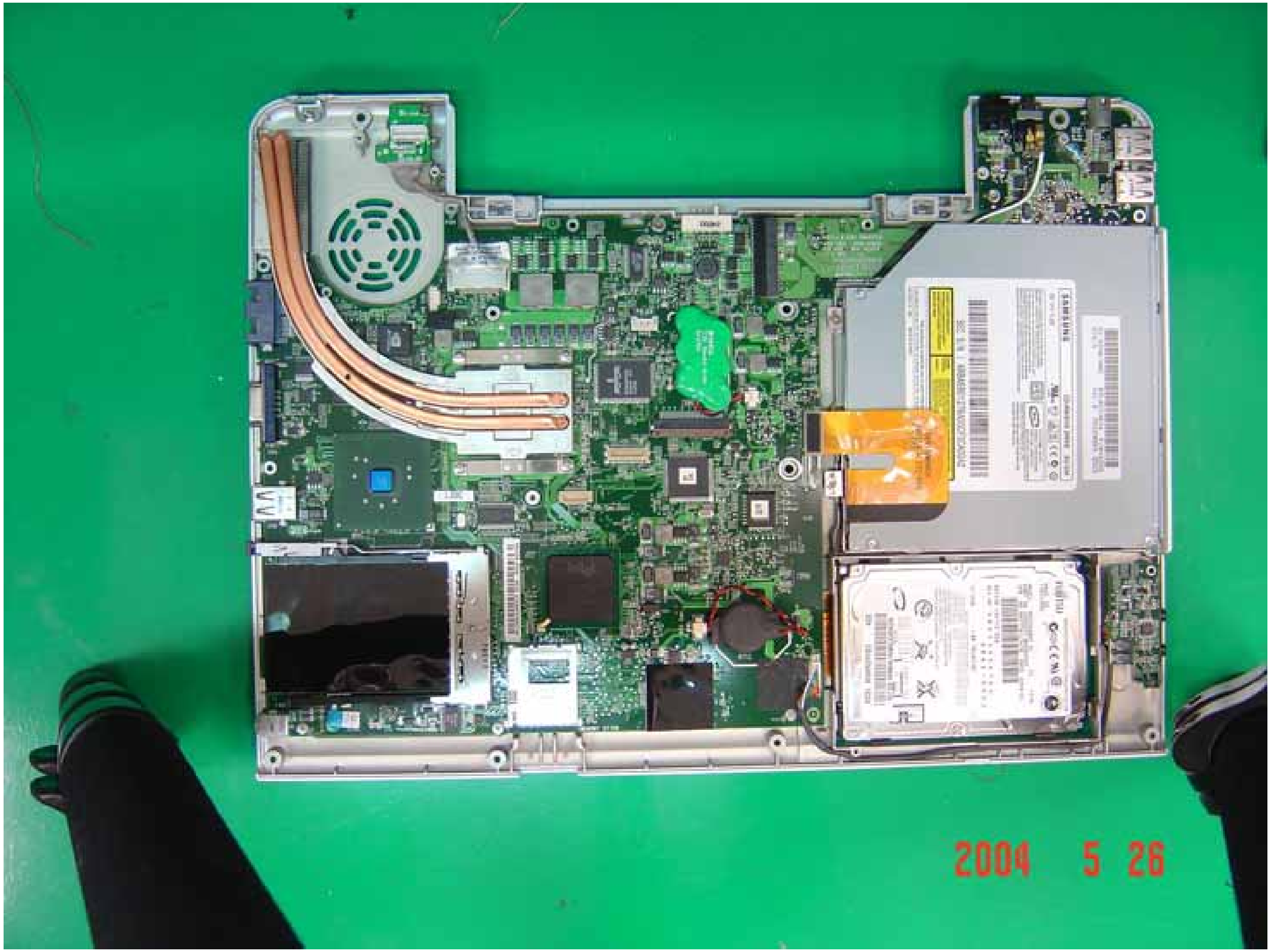
Samsung X30

Samsung X30

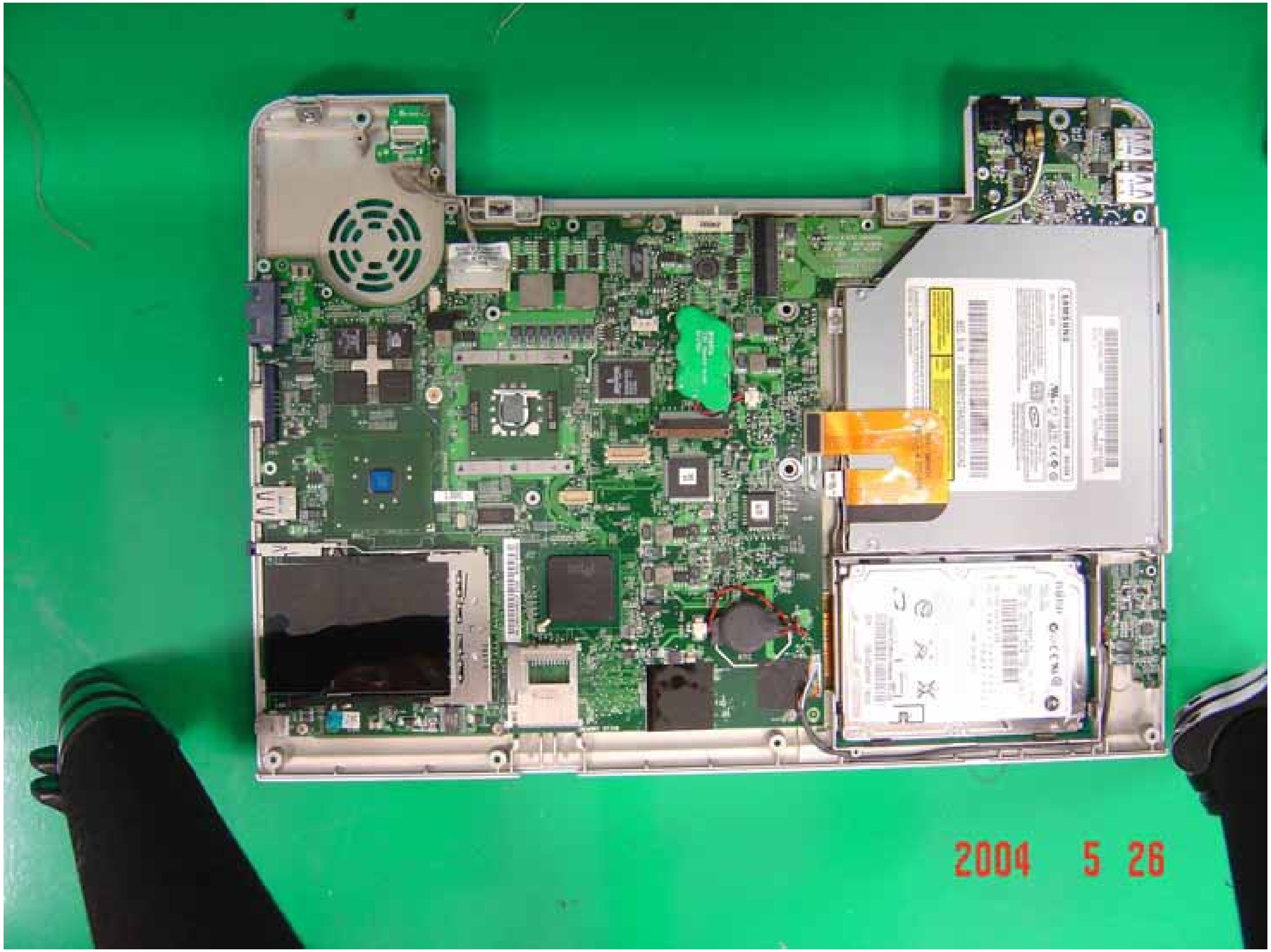
Samsung X30

Samsung X30

Samsung X30



Samsung X30



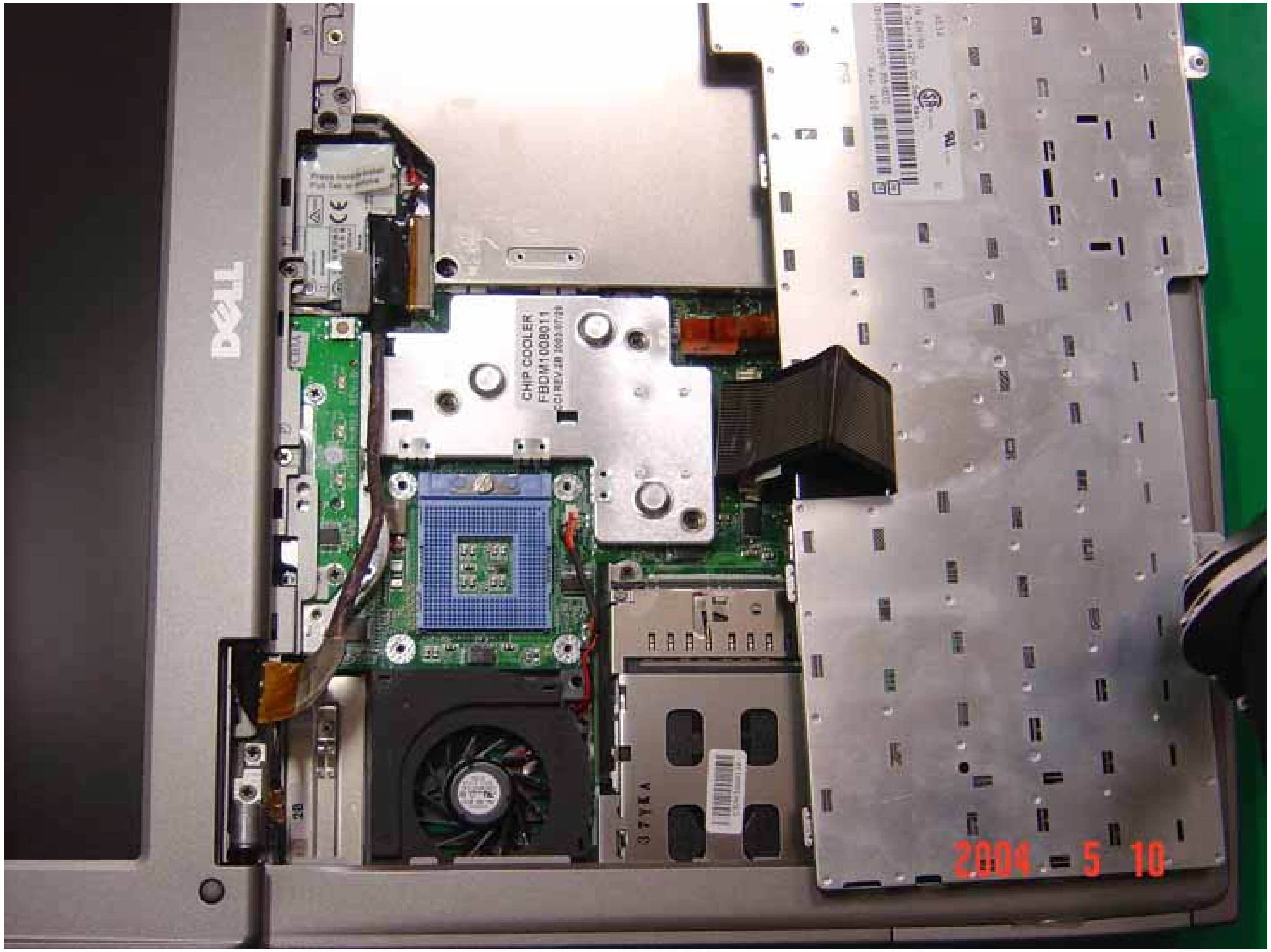
Dell P2

Dell P2

Dell P2

Dell P2

Dell P2



ECS 556

ECS 556

ECS 556

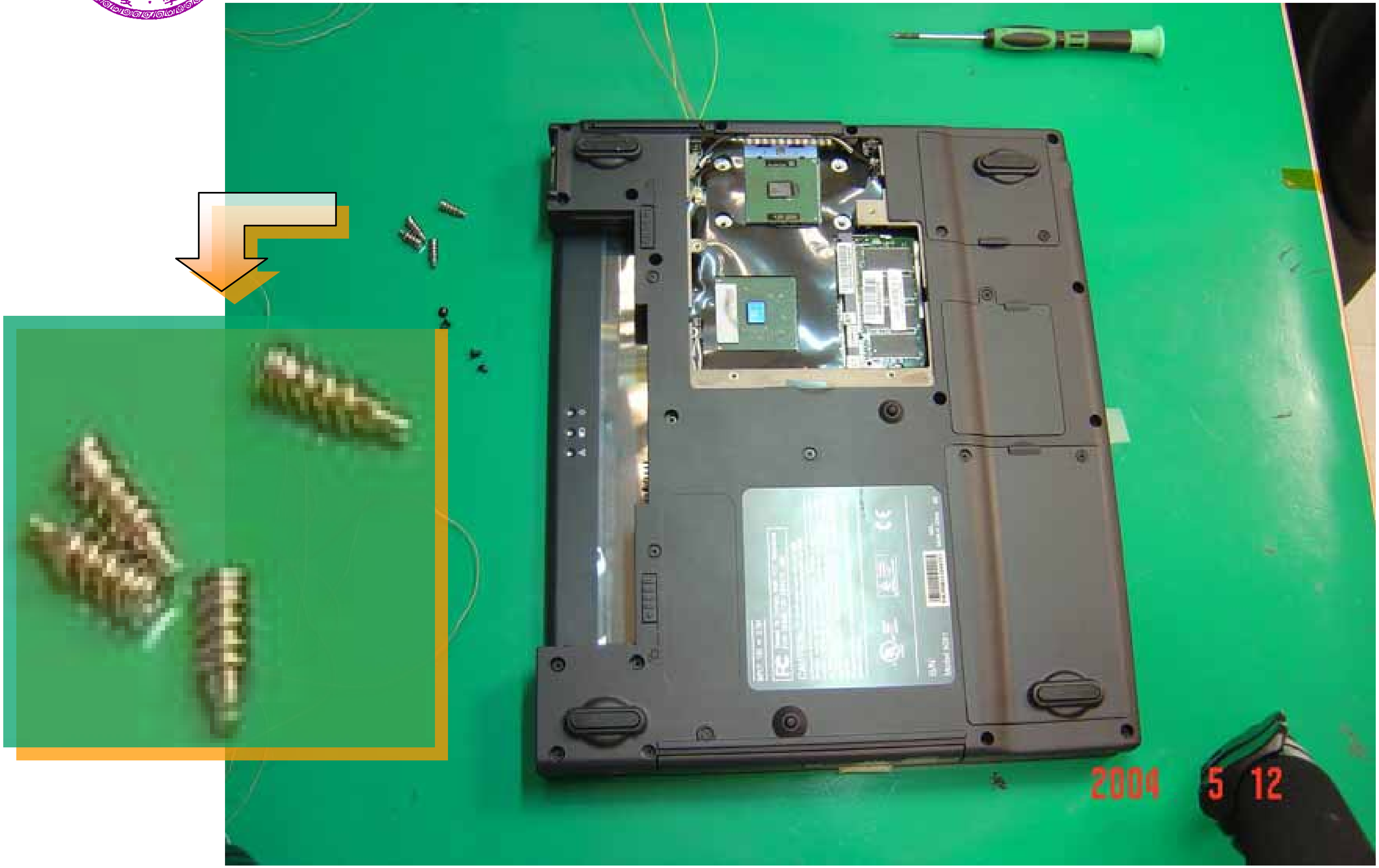
ECS 556

ECS 556

Clevo E260

Clevo E260

Clevo E260

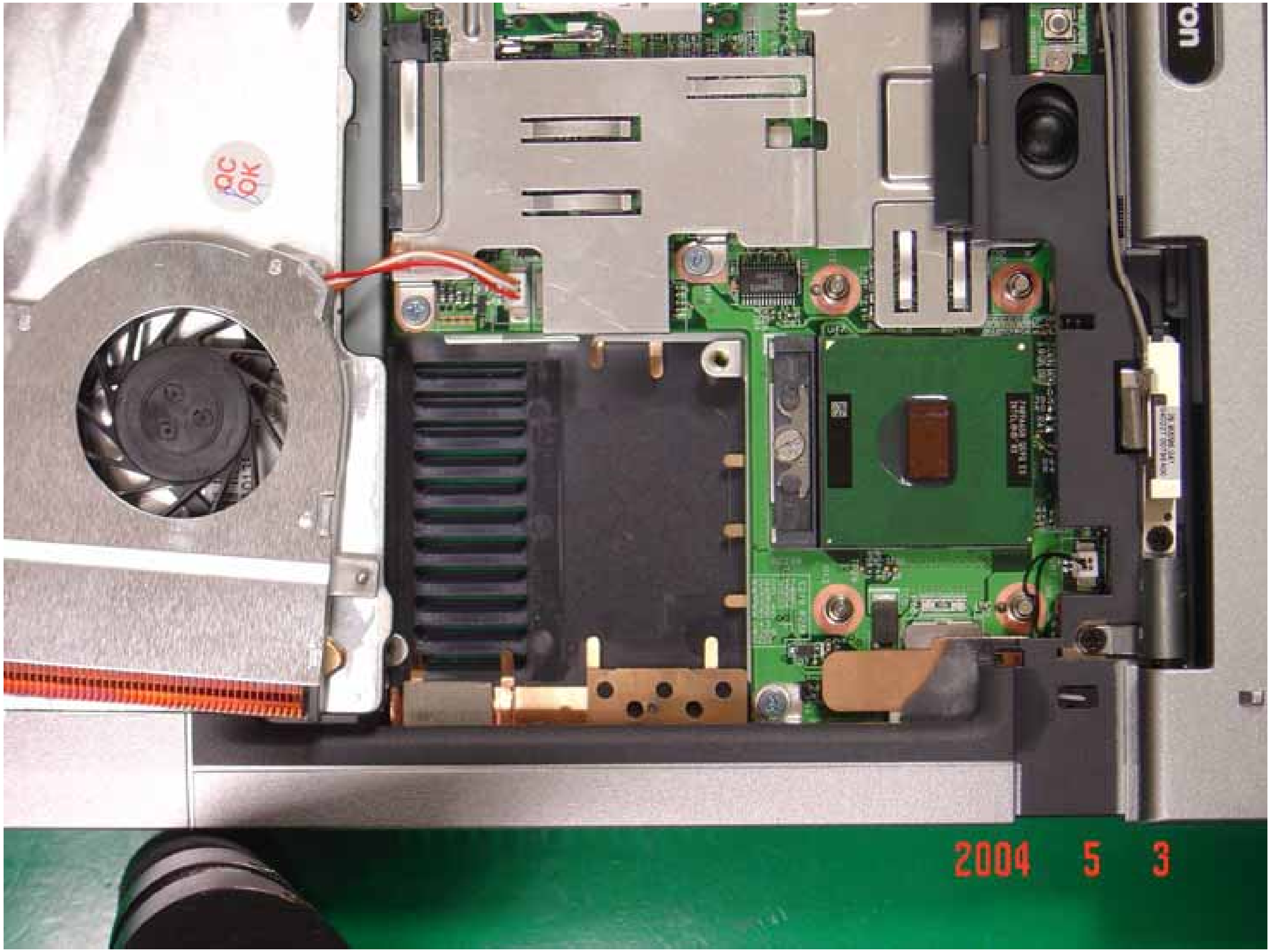


Wistron D2U

Wistron D2U

Wistron D2U

Wistron D2U



Summary

- E/E structure
- ME layout
  - Meet thermal/ME requirement
  - Less parts
  - Less steps
- CPU access
  - From KB
  - From bottom

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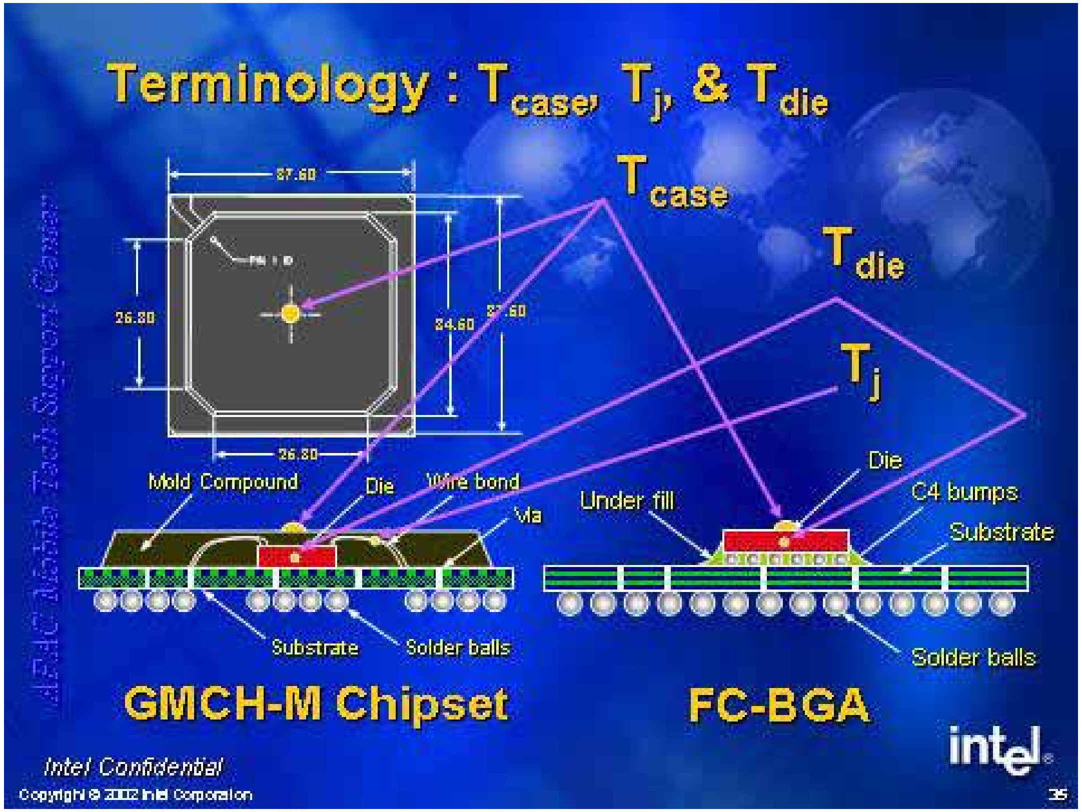
Specification

- Temperature
  - CPU
  - Chipset / MEM
  - Skin
- Contact pressure
- Environment
  - Acoustic noise
    - Sound pressure
    - Sound power
    - Sound quality
  - Applications

Specification

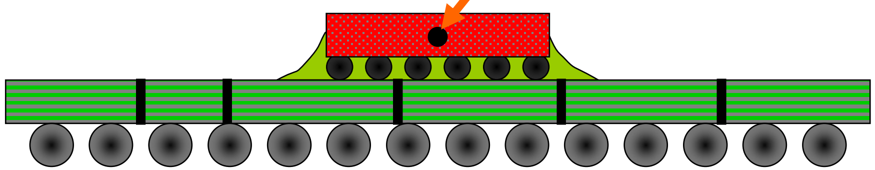
- CPU
  - Tj < 100 ^oC
  - Static pressure < 100 psi
- GMCH
  - Tj < 110 ^oC
- MEM
  - Tc < 85 ^oC



CPU thermal specification

- T_j spec.

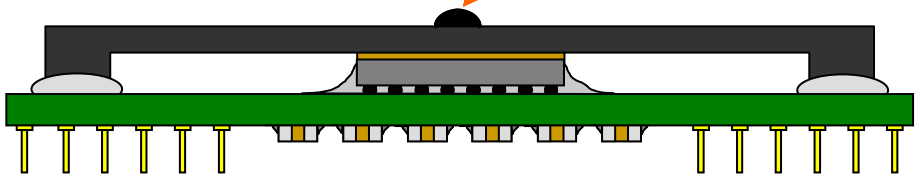
100 °C



BGA

- T_c spec.

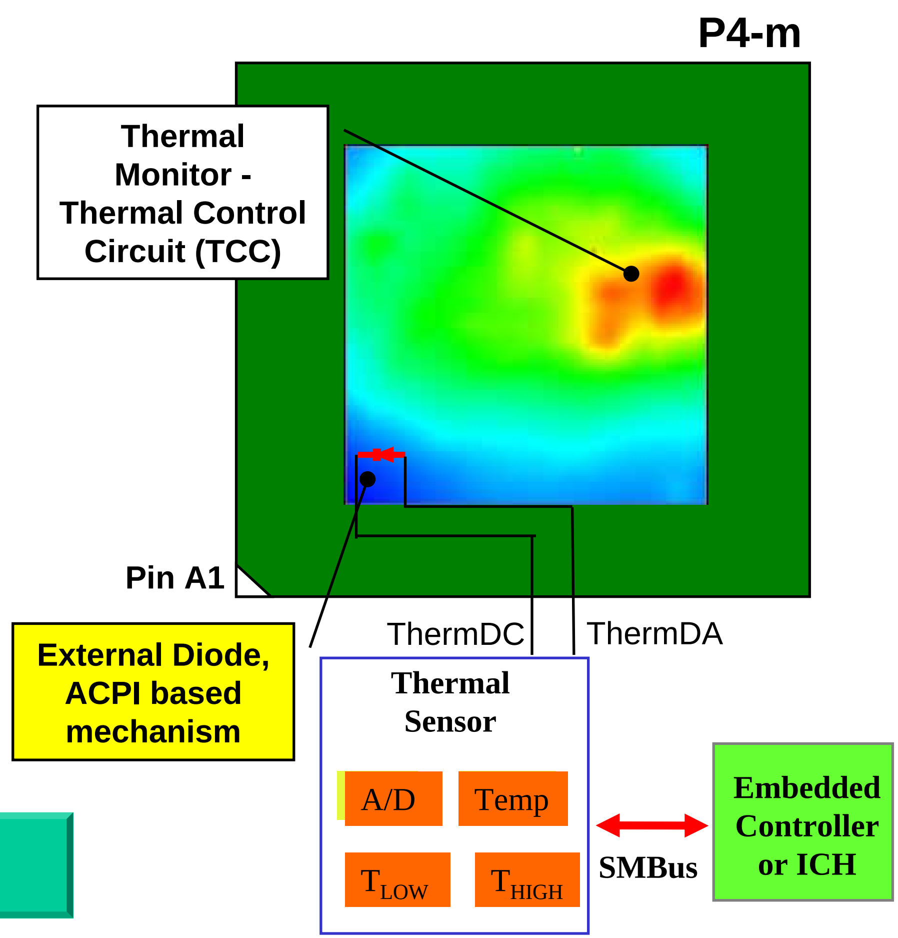
70 °C or 76 °C



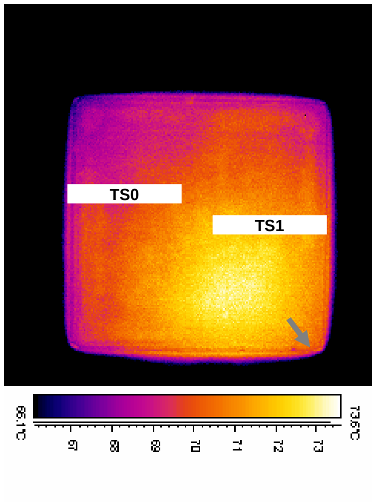
PGA

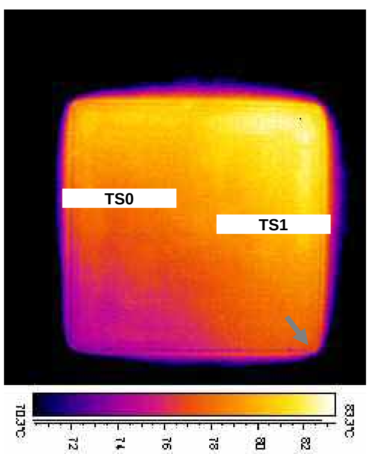
Thermal monitor & Diode

- Thermal Monitor is Intel's name for on-die thermal management
  - On-die Thermal Control Circuit (TCC set at 100 °C) automatically engages throttling located at die hotspot
- Diode
  - On-die diode with off-chip A/D
  - Not located at hottest part of die
- Diode reading Demo



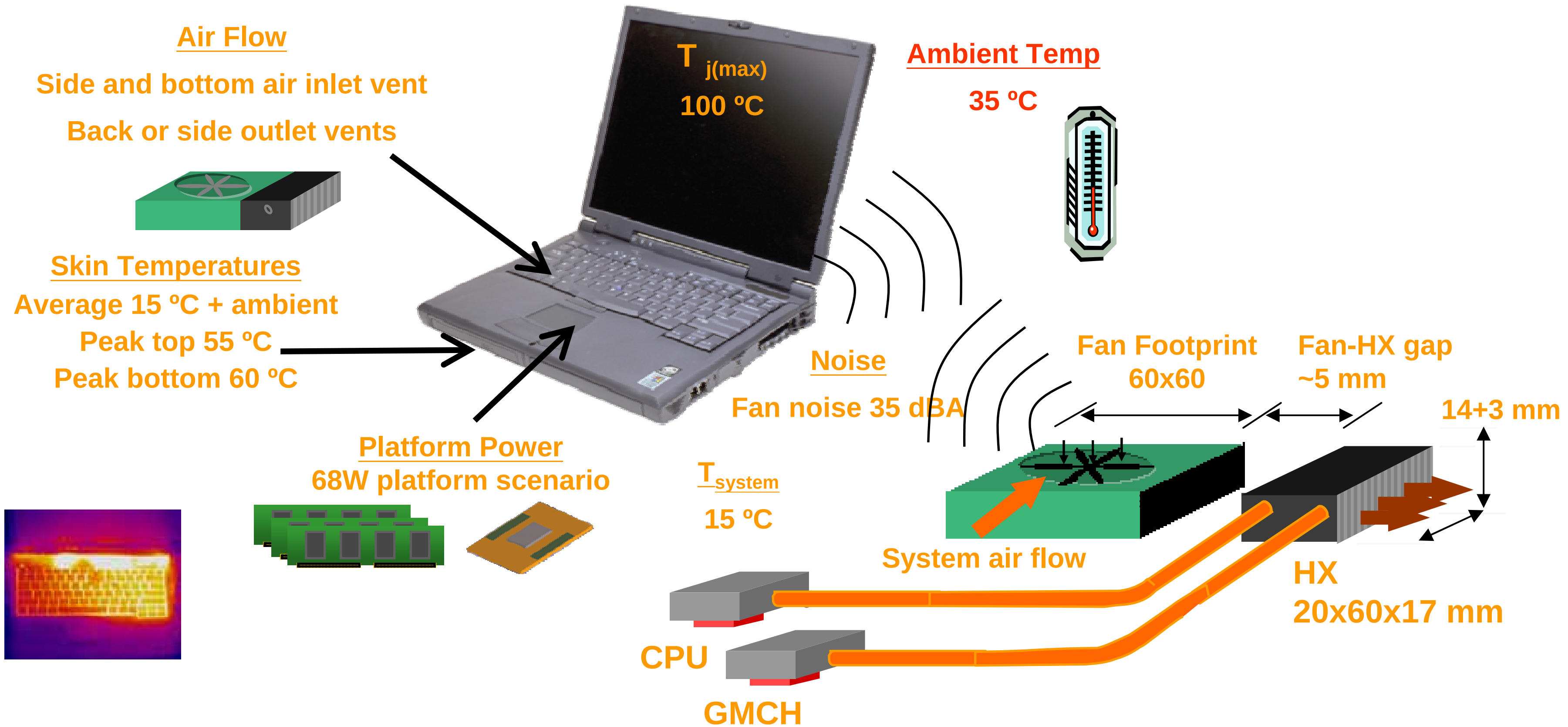
Digital Thermal Sensors (DTS)





- Chipset (GMCH) digital thermal sensor
- Two hotspot regions
  - TS0: DDR Bus region
  - TS1: PCI Express Graphics (PEG) and 3D Graphics regions
  - Top IR image: Internal Graphics Stress Application
  - Bottom IR image: DDR Stress application (TPT)
- Accuracy projected to be +/- 5°C near Tj-max

Environment Specification



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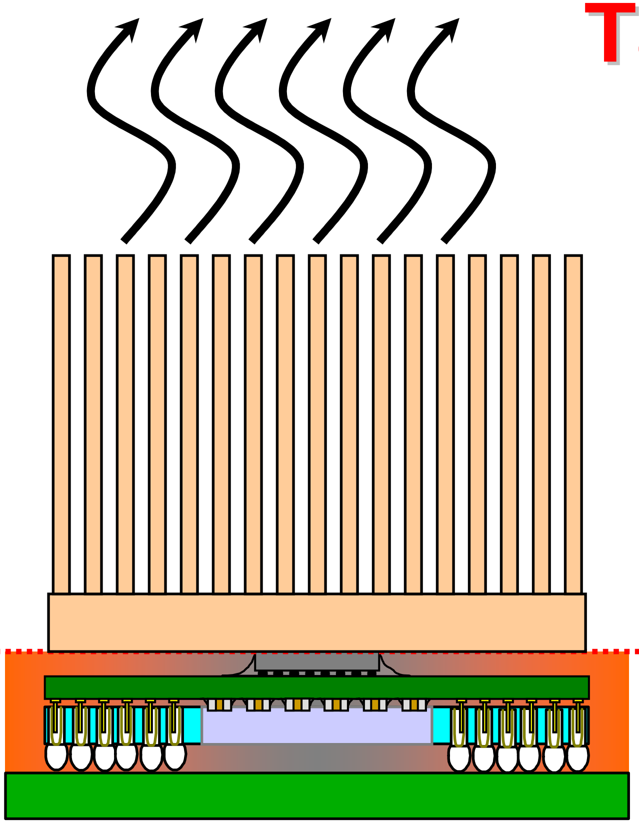
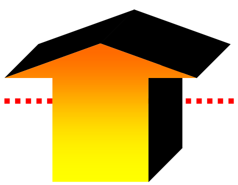
Heat generated by CPU

Ta (ambient)



Heat flows across heat sink (conduction)

Heat flows into ambient (convection)

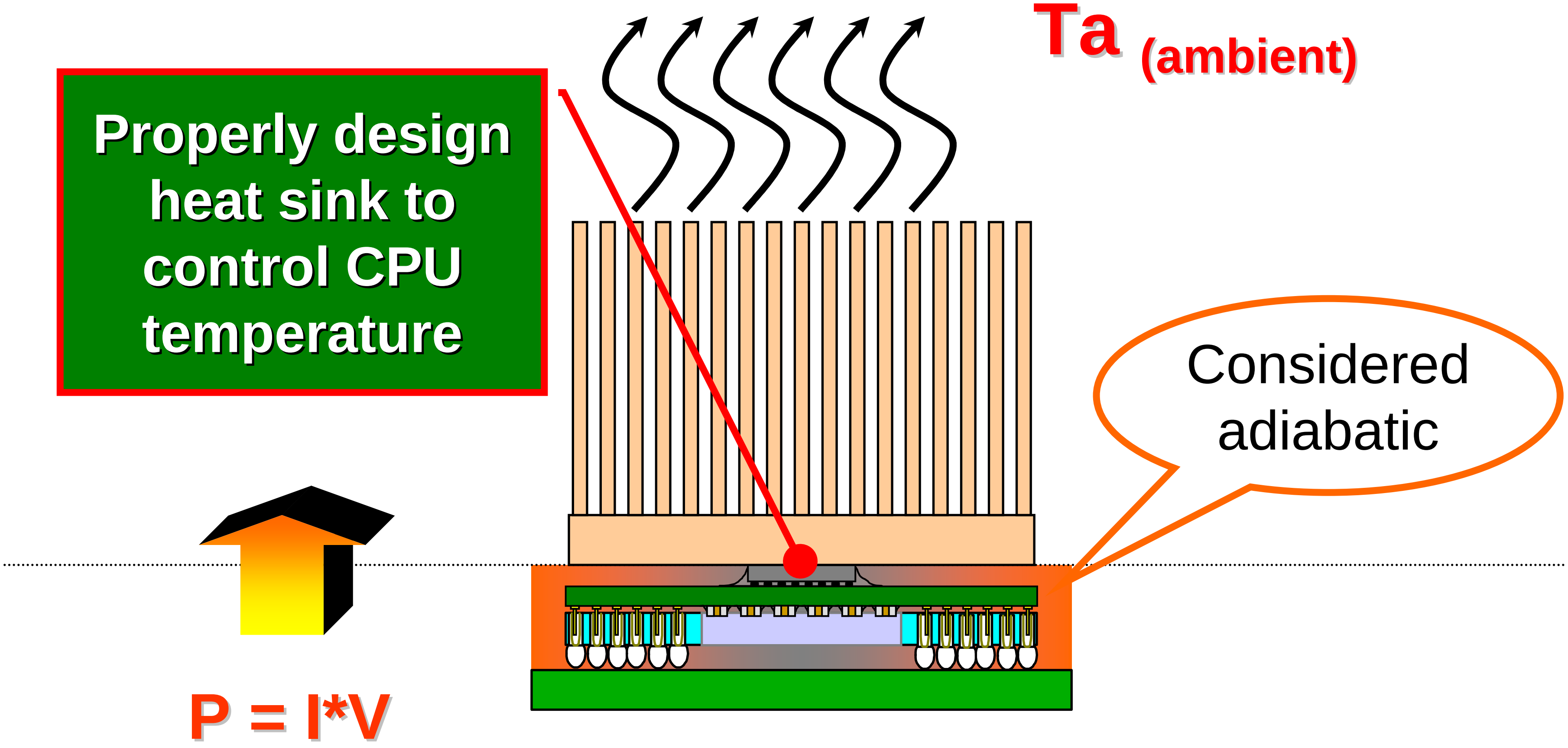


Heat generated inside CPU

P = I*V

Constant heat flux

CPU heat sink design



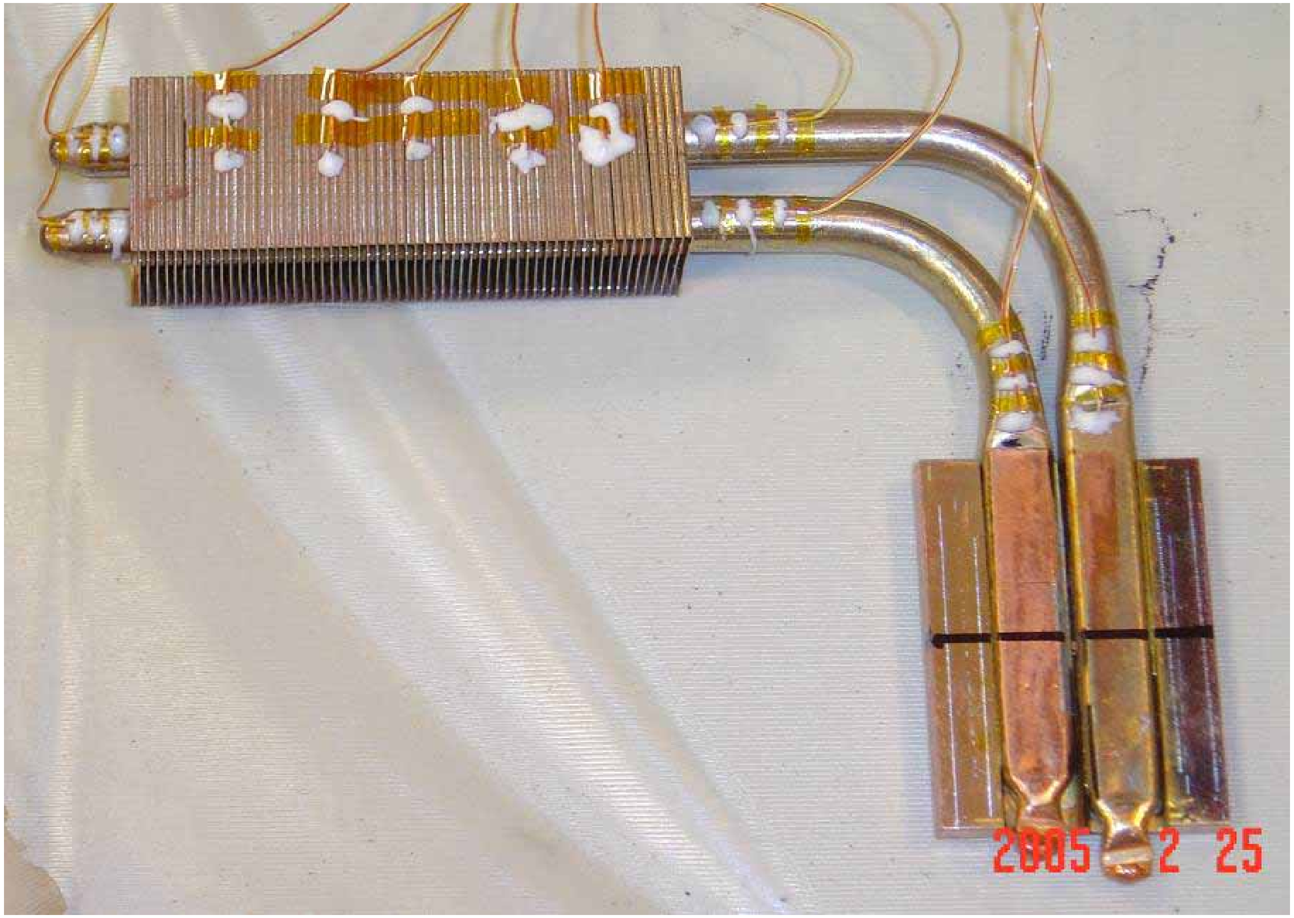
Design proper thermal resistance

Remote Heat Exchanger

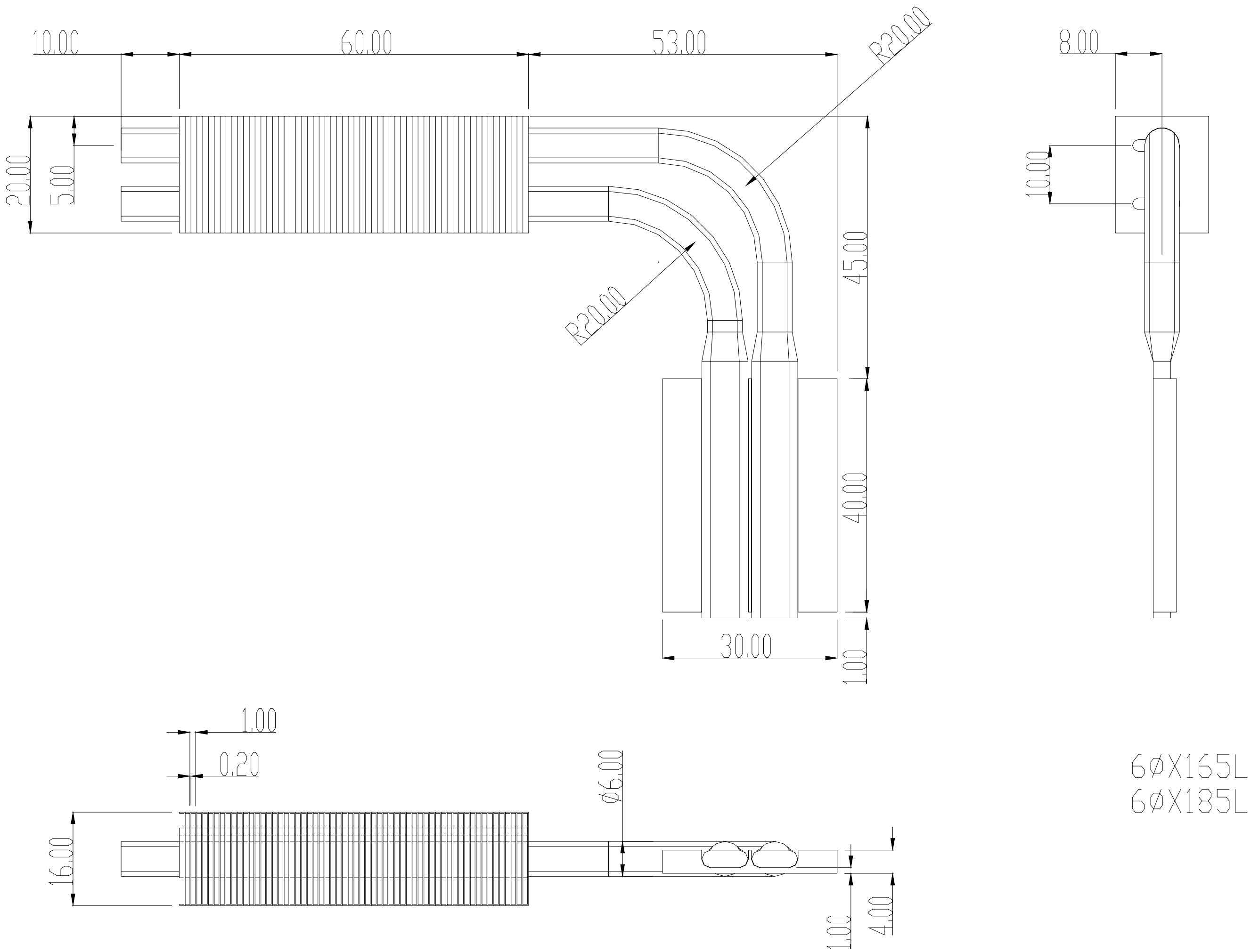
- Main components
  - CPU block
  - Thermal Interface Material (TIM)
  - Heat pipe
  - Heat Exchanger
- Fan (blower)

Remote Heat Exchanger

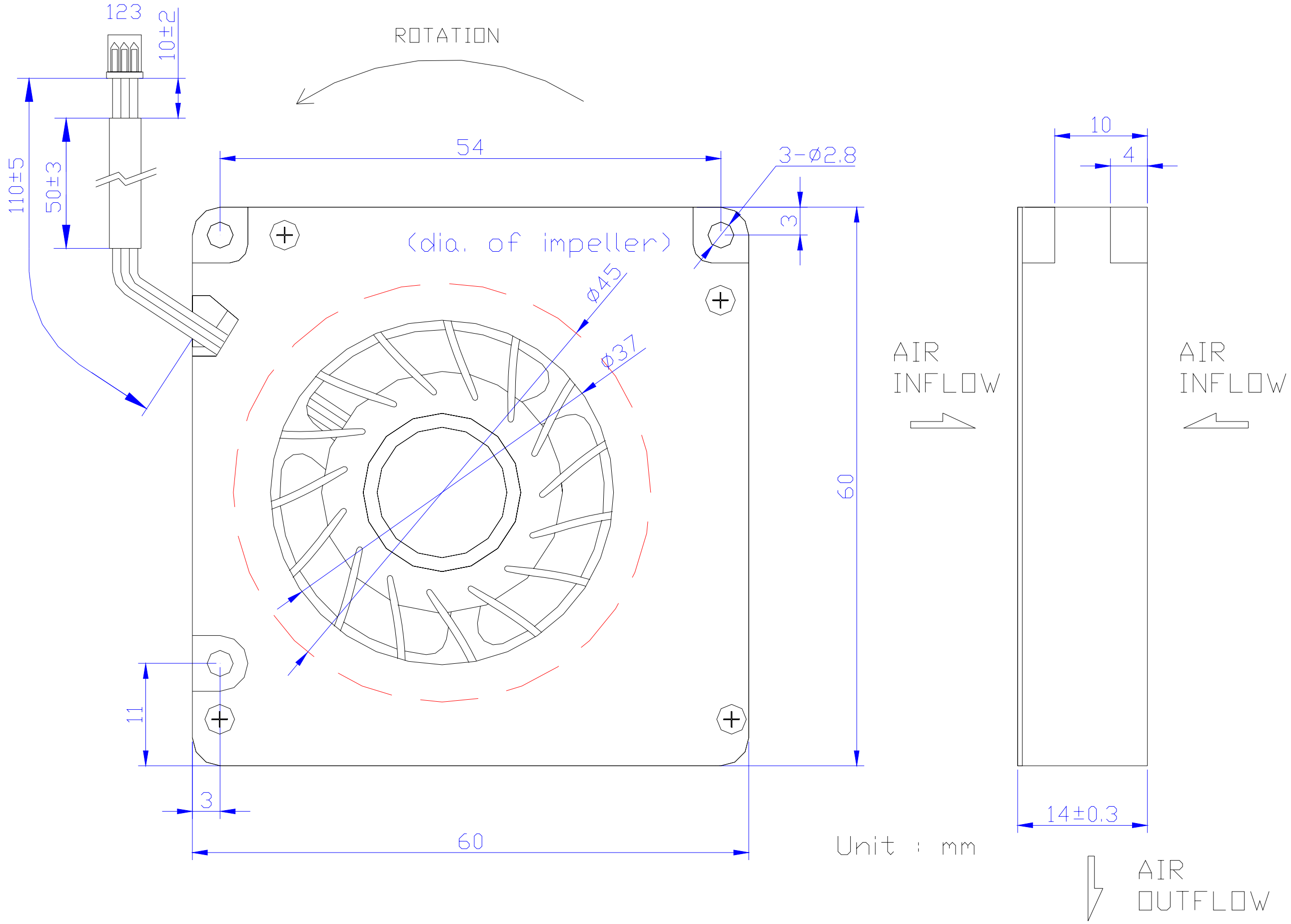
Remote Heat Exchanger (RHE)



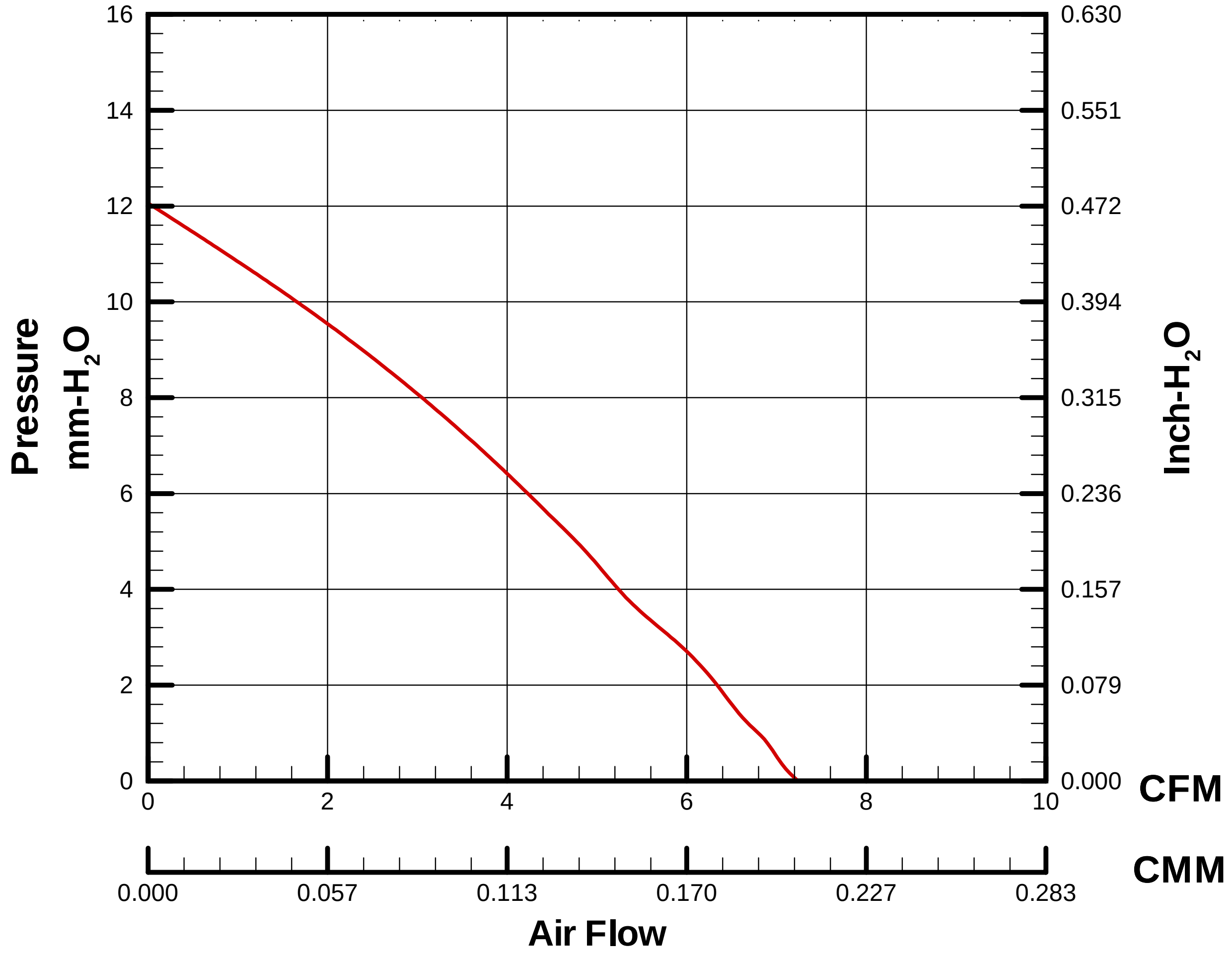
Remote Heat Exchanger



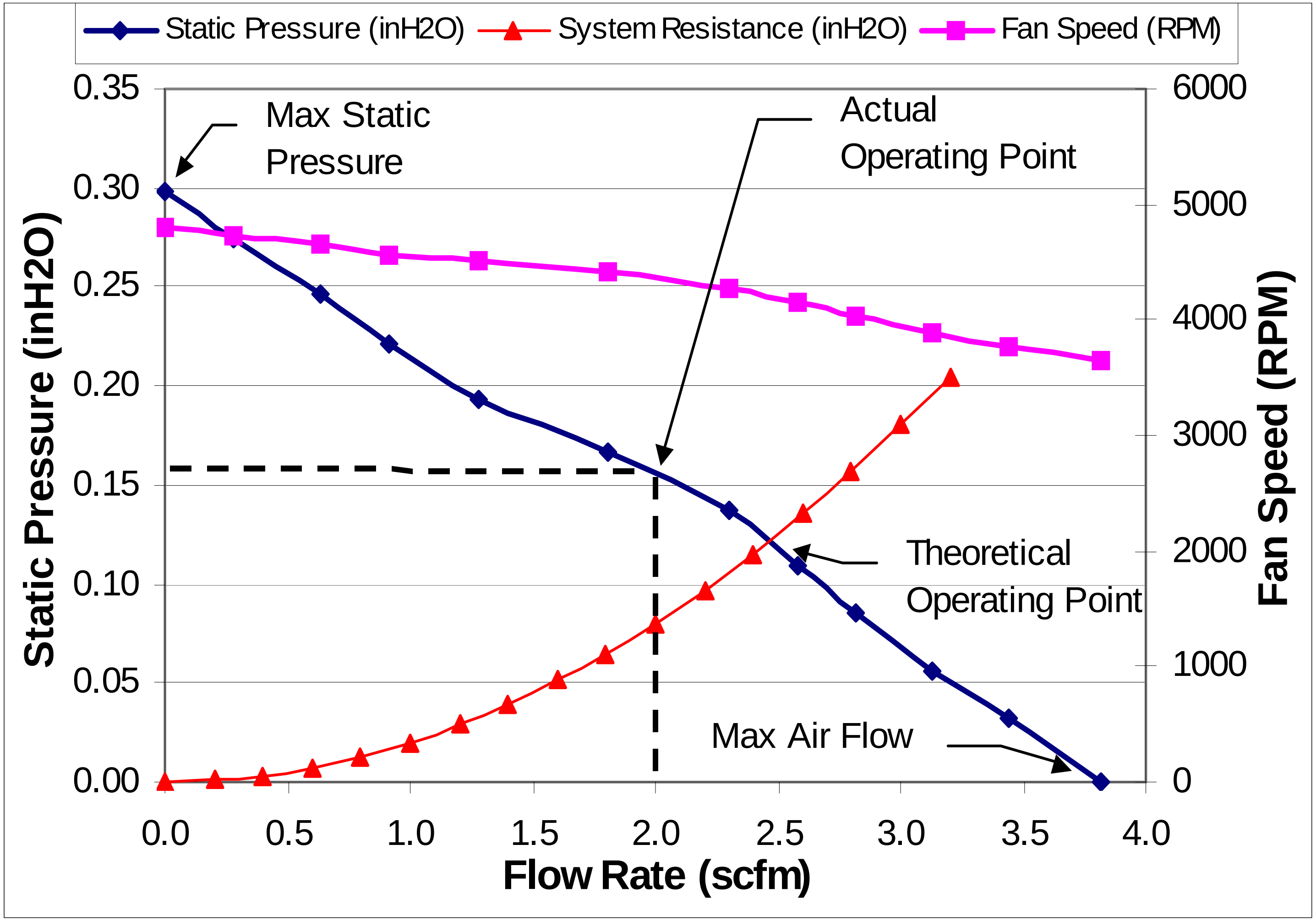
Blower


123
10±2
ROTATION
110±5
50±3
54
3-Ø2.8
10
4
3
(dia. of impeller)
Ø45
Ø37
60
AIR
INFLOW
AIR
INFLOW
11
3
60
14±0.3
Unit : mm
AIR
OUTFLOW

Blower P-Q curve



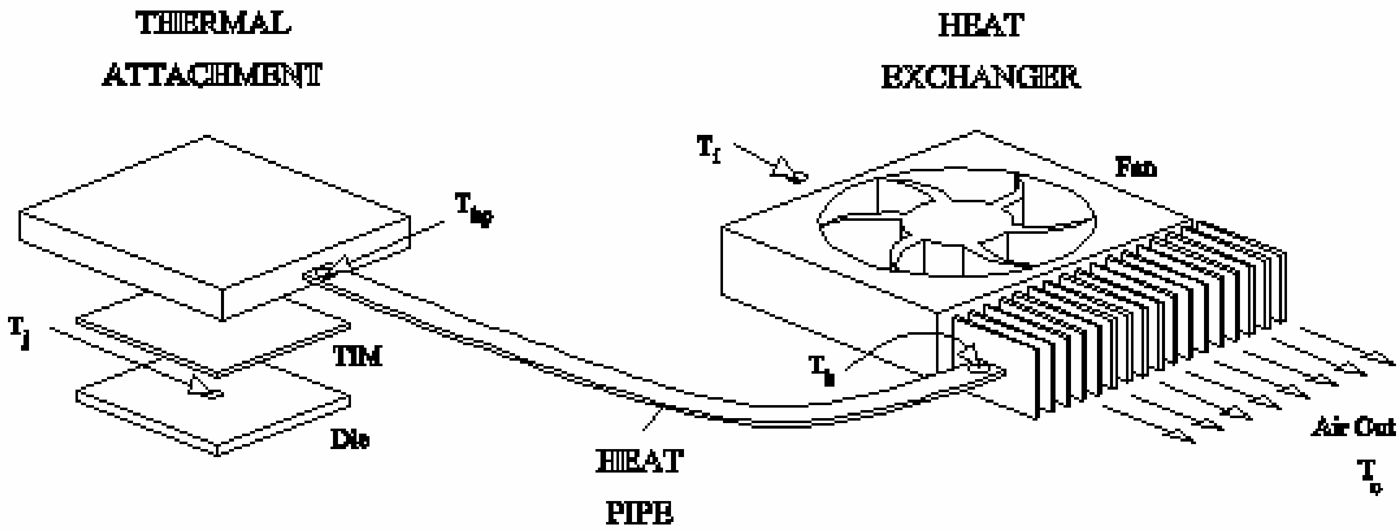
P-Q curve & Thermal Resistance



Thermal Resistance

Remote Heat Exchanger (RHE)

$$\theta_{j-a} \le 1.5\ {}^{\circ}C/W$$

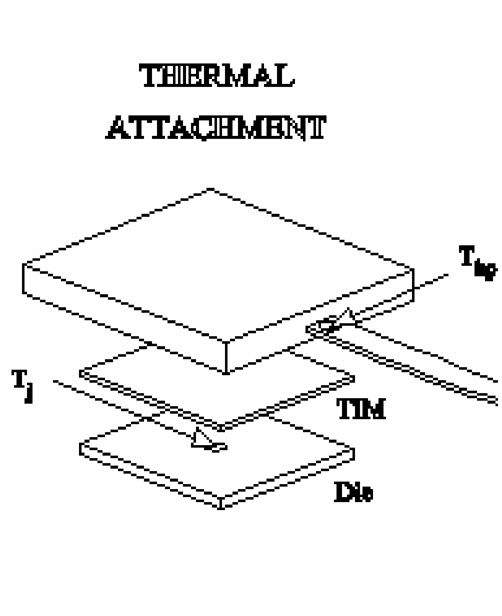


$$\theta_{j-a} = \frac{T_j - T_a - T_{sys}}{P_{CPU}}$$

$$\theta_{j-a} \approx \theta_{j-HP} + \theta_{HP-HX} + \theta_{HX-a}$$

Thermal Resistance

Junction to heat pipe thermal resistance

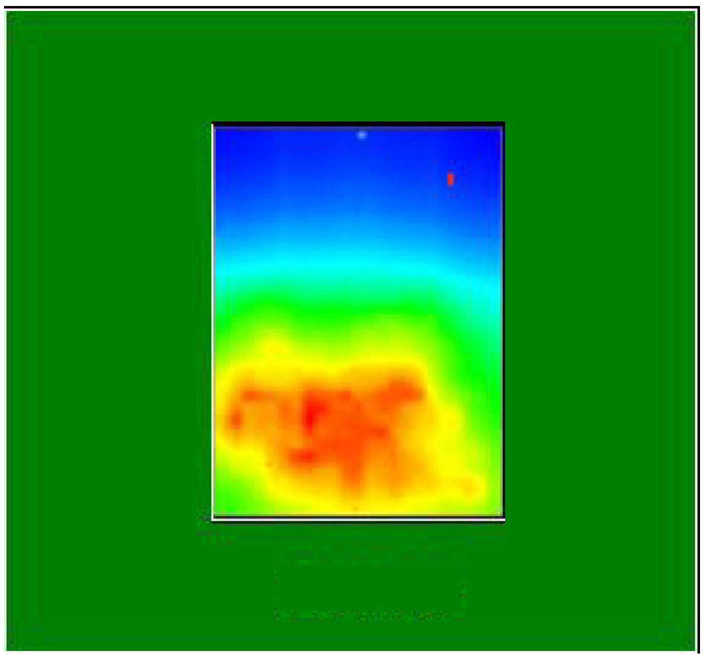


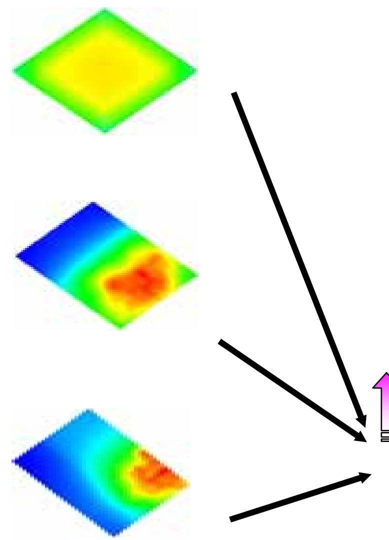
$$\theta_{j-HP} \cong \theta_{Si} + \theta_{TIM} + \theta_{evaporator} = \frac{T_j - T_{HP}}{P_{CPU}}$$

Thermal Resistance

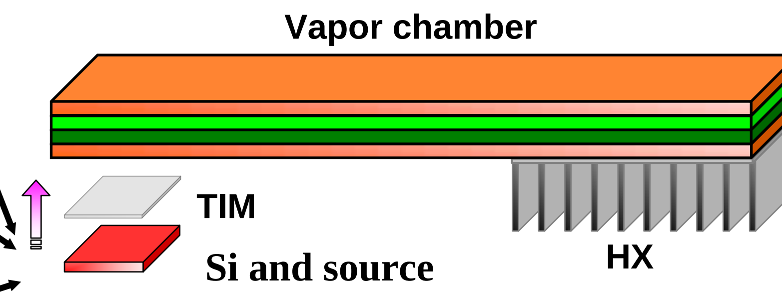
Density Factor (DF) $\Rightarrow \theta_{Si}$

DF = 1.1 ~ 3.0





DF = $\theta_{j\text{-hp, actual}} / \theta_{j\text{-hp,ref}}$



$$DF \equiv \frac{\theta_{real}}{\theta_{reference}}$$

$\Theta_{reference}$ = 0.4 C/W

Thermal Resistance

- Density Factor (DF)
  - Die size
  - core size / Cache size / Core number
  - Trace width
  - Thermal design power

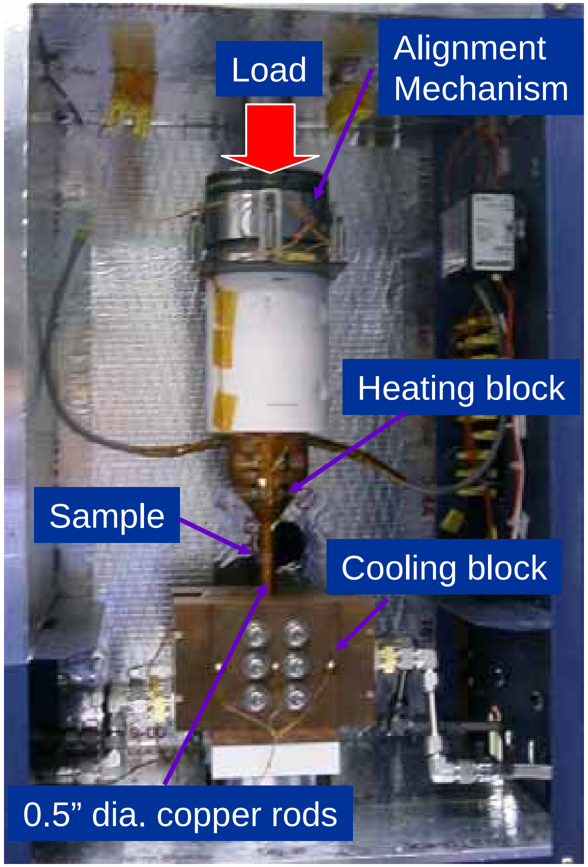
Thermal Resistance

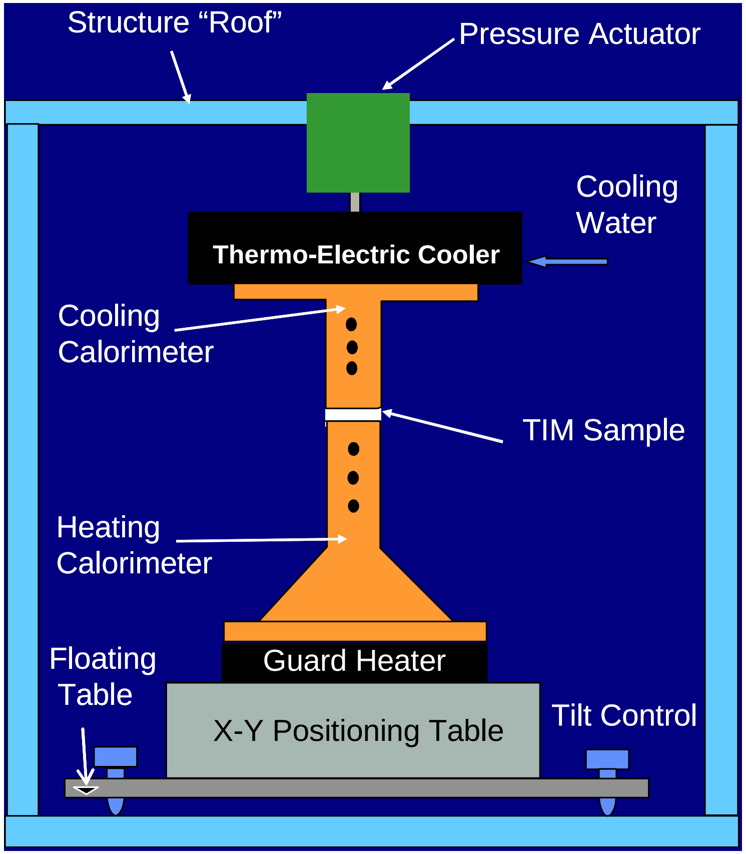
Thermal Interface Material (TIM) thermal resistance

$\Rightarrow \theta_{TIM}$

ASTM TIM tester

$$\theta_{TIM} = \frac{BLK}{K_{TIM}} + R_c$$





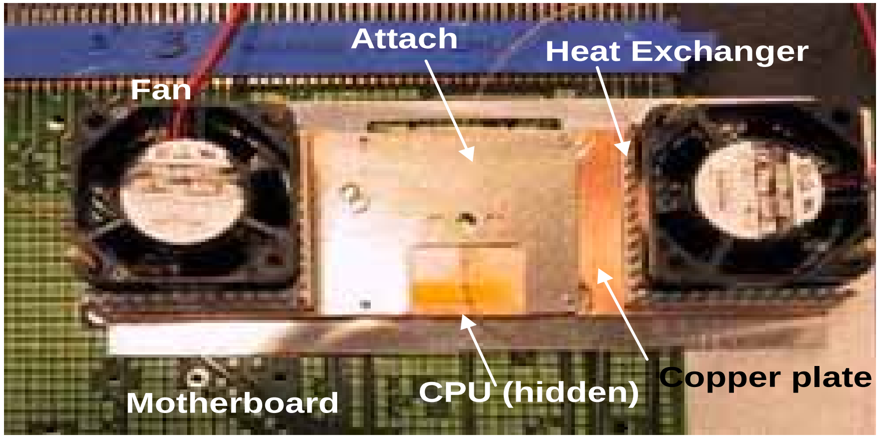
BLK is the thickness of the TIM under usage

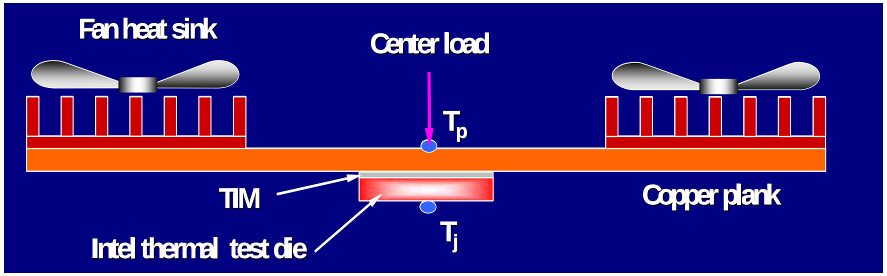
Rc is the contact resistance between the TIM and surfaces

Thermal Resistance

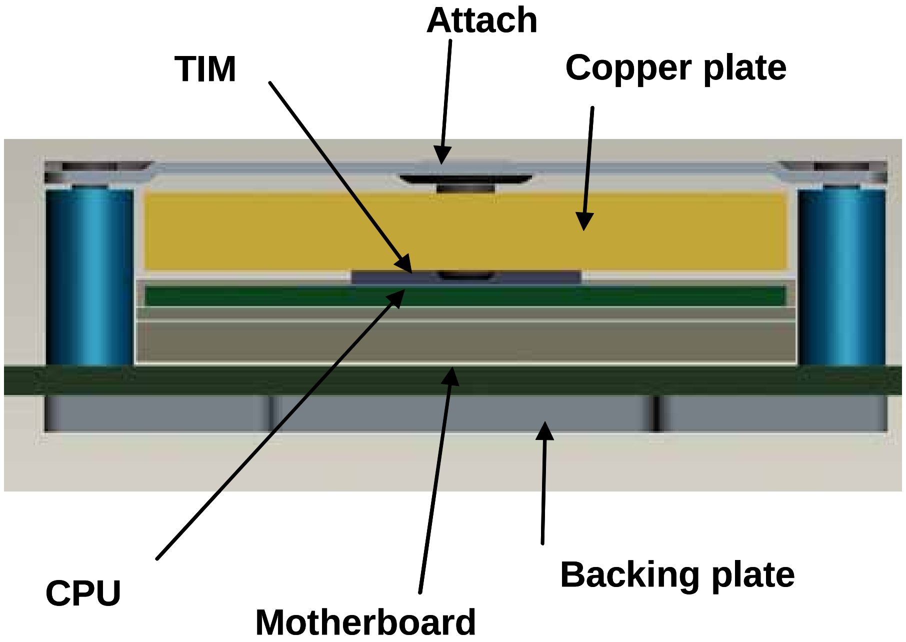
Thermal Interface Material (TIM) thermal resistance

$$\Rightarrow \theta_{TIM}$$





Mobile TIM tester



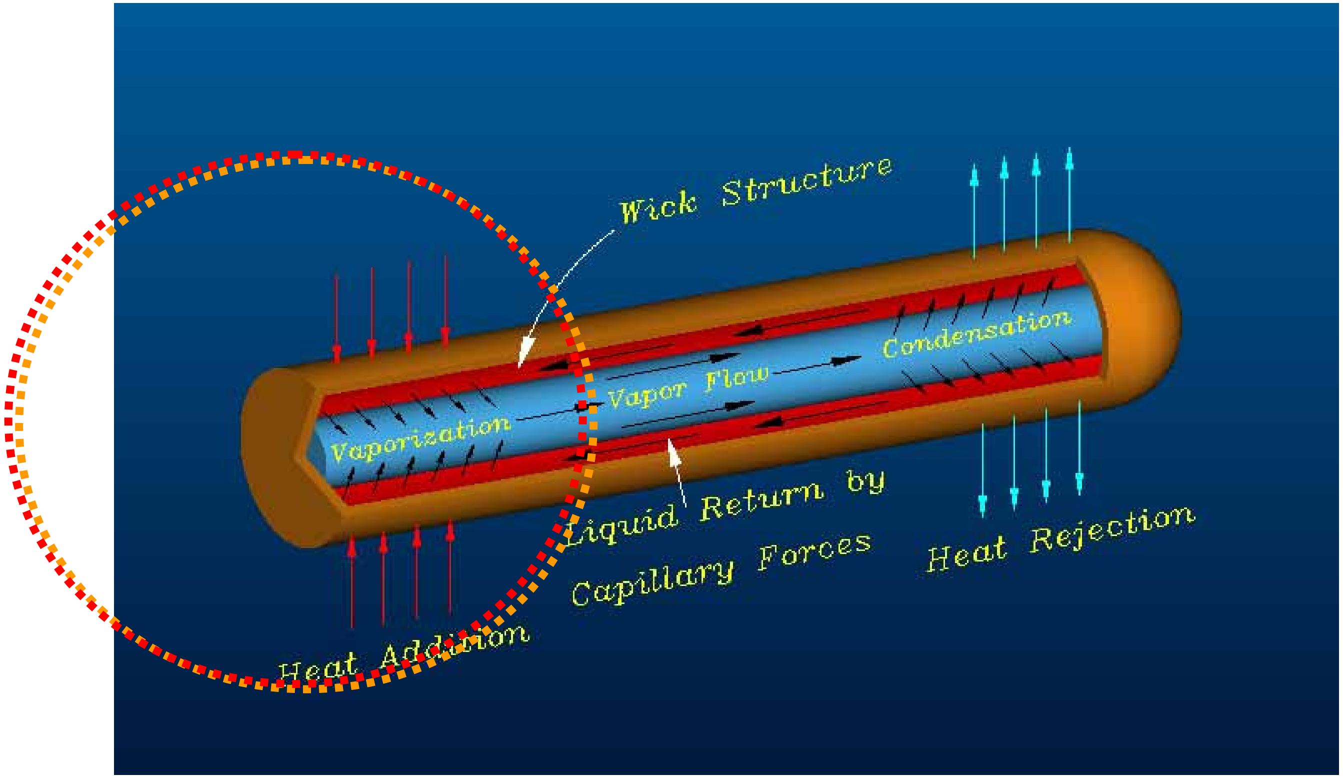
Attachment & reliability

Thermal Resistance

- Thermal interface material
  - Thermal resistance
    - Conductivity
    - ASTM vs. Mobile tester
  - Reliability
  - Productivity
  - Phase change / grease / metallic
  - Cost

Thermal Resistance

Evaporator thermal resistance $\Rightarrow \theta_{evaporator}$

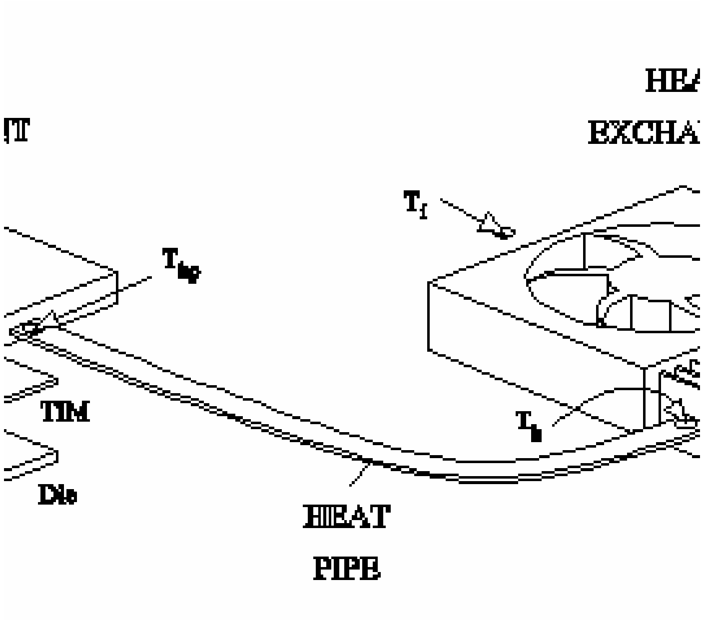


$$\theta_{evaporator} \equiv \frac{T_{block} - T_{HP}}{P_{CPU}}$$

Thermal Resistance

Heat pipe thermal resistance

$$\theta_{HP} \le 0.05 \, {}^{\circ}C/W$$



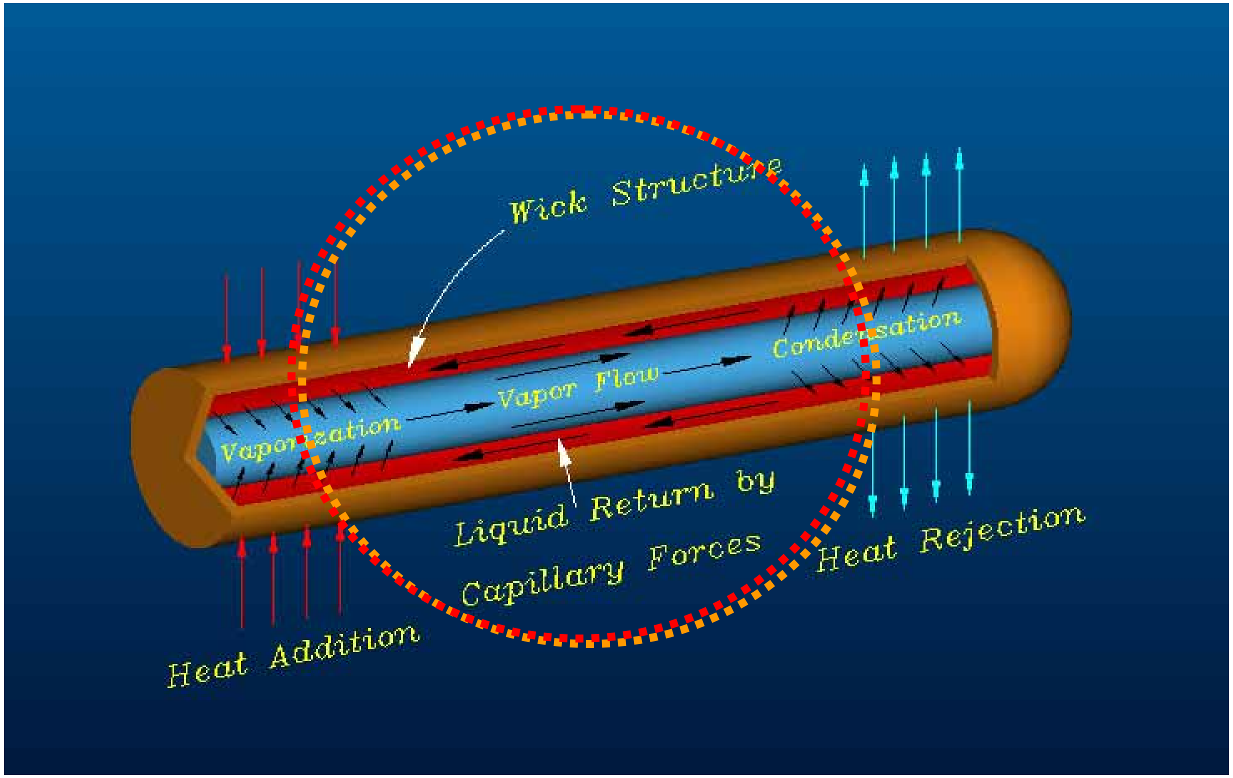
$$\theta_{HP} \equiv \frac{T_{HP} - T_{HX}}{P_{CPU}}$$

Thermal Resistance

- Heat pipe
  - Wick structure
    - Groove / mesh / powder
  - Liquid
  - Diameter
  - Length
- Majority in NB industry
  - Powder
  - Water

Thermal Resistance

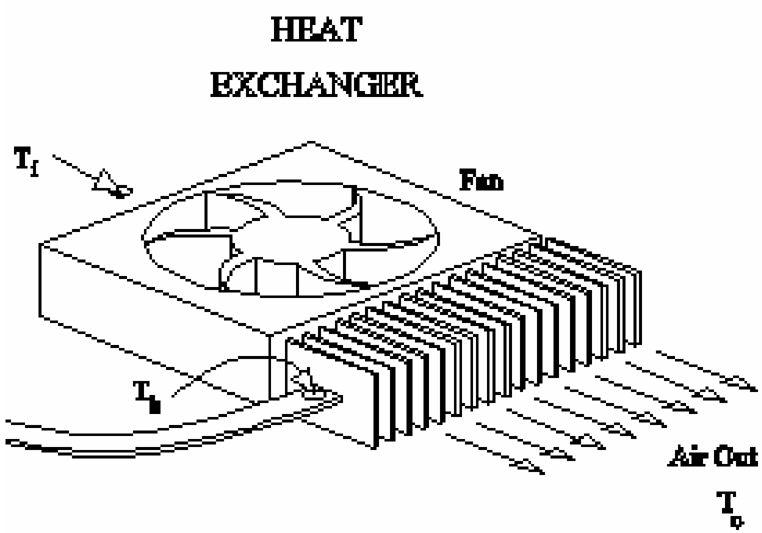
HP thermal resistance $\Rightarrow \theta_{HP}$



$$\theta_{HP} \equiv \frac{T_{HP} - T_{HX}}{P_{CPU}}$$

Thermal Resistance

Heat exchanger thermal resistance

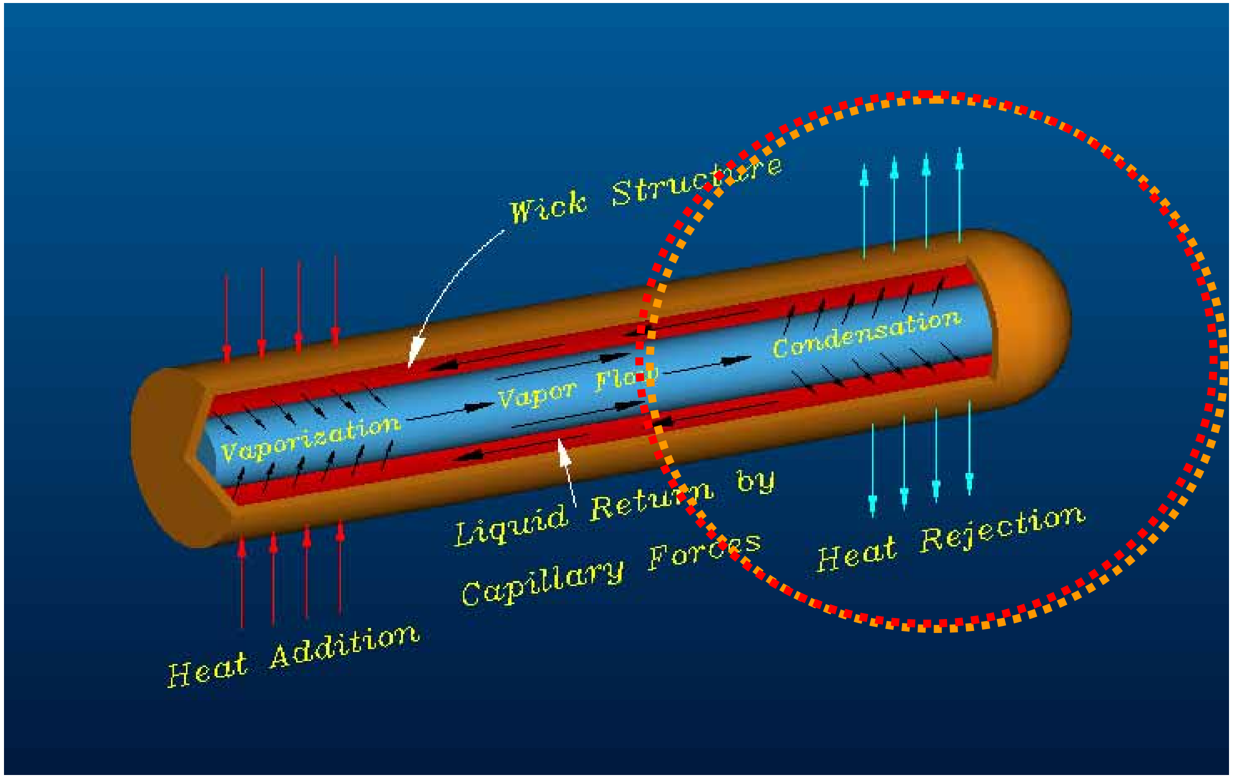


$$\theta_{HX-a} = \theta_{condenser} + \theta_{fin}$$

$$\theta_{HX-a} \equiv \frac{T_{HX} - T_a}{P_{CPU}}$$

Thermal Resistance

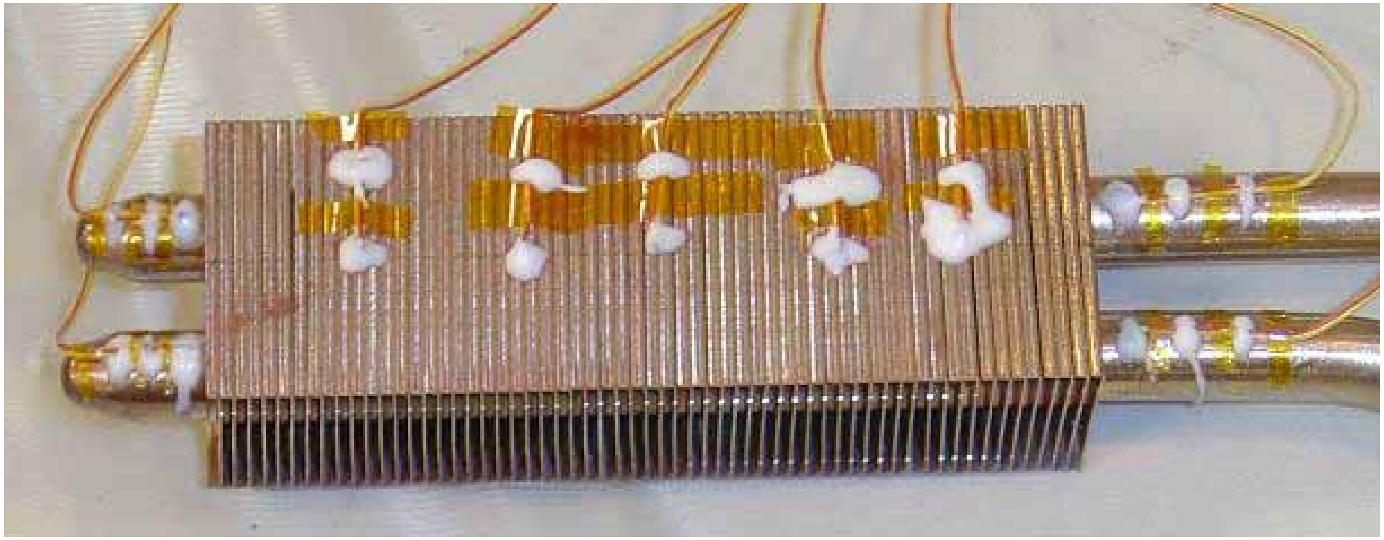
Condenser thermal resistance $\Rightarrow \theta_{condenser}$



$$\theta_{condenser} \equiv \frac{T_{HX} - T_{fin}}{P_{CPU}}$$

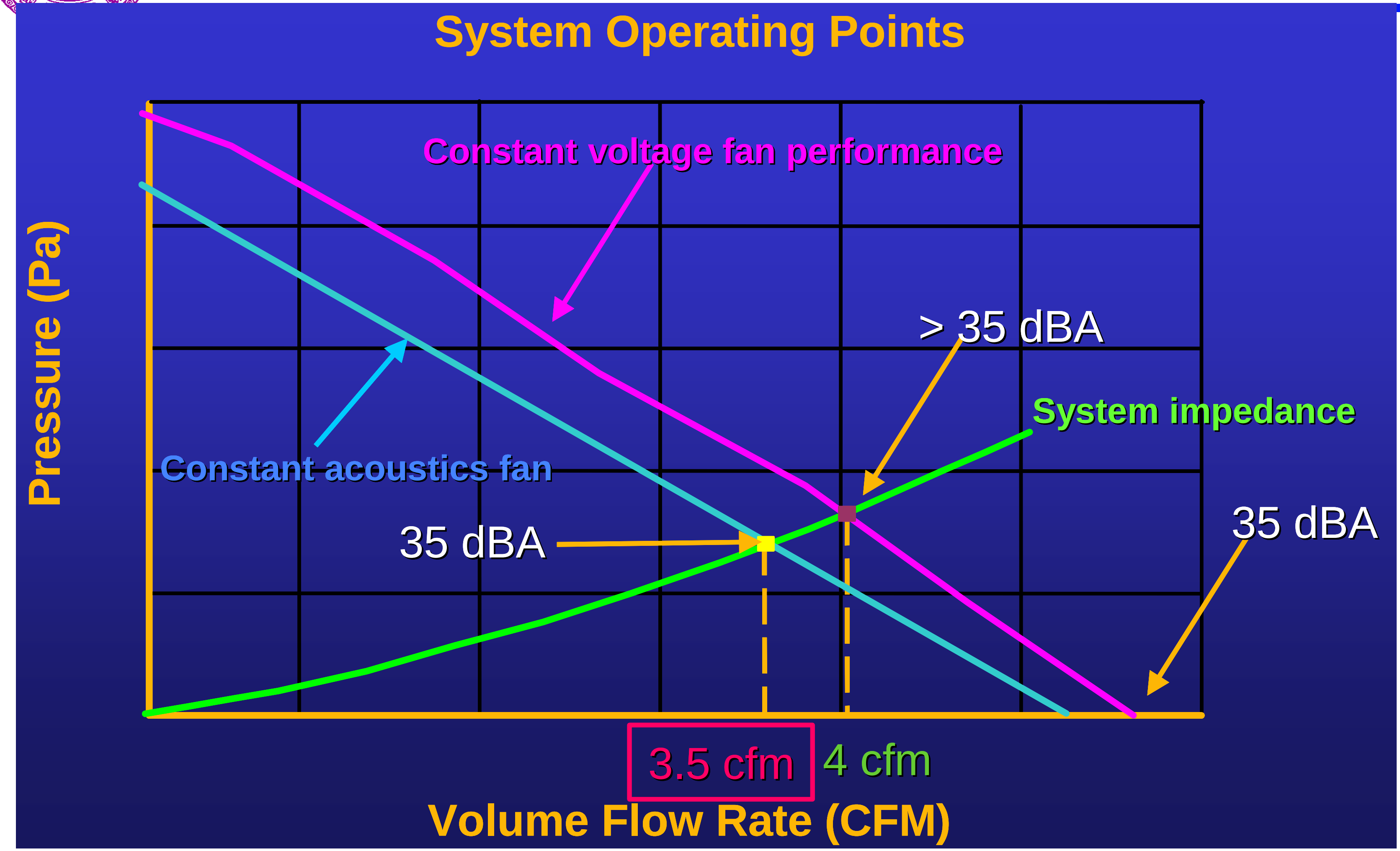
Thermal Resistance

Fin thermal resistance



$$\theta_{fin} \equiv \frac{T_{fin,ave} - T_a}{P_{CPU}}$$

CV vs. CA


System Operating Points
Constant voltage fan performance
> 35 dBA
System impedance
Constant acoustics fan
35 dBA
35 dBA
Pressure (Pa)
3.5 cfm
4 cfm
Volume Flow Rate (CFM)

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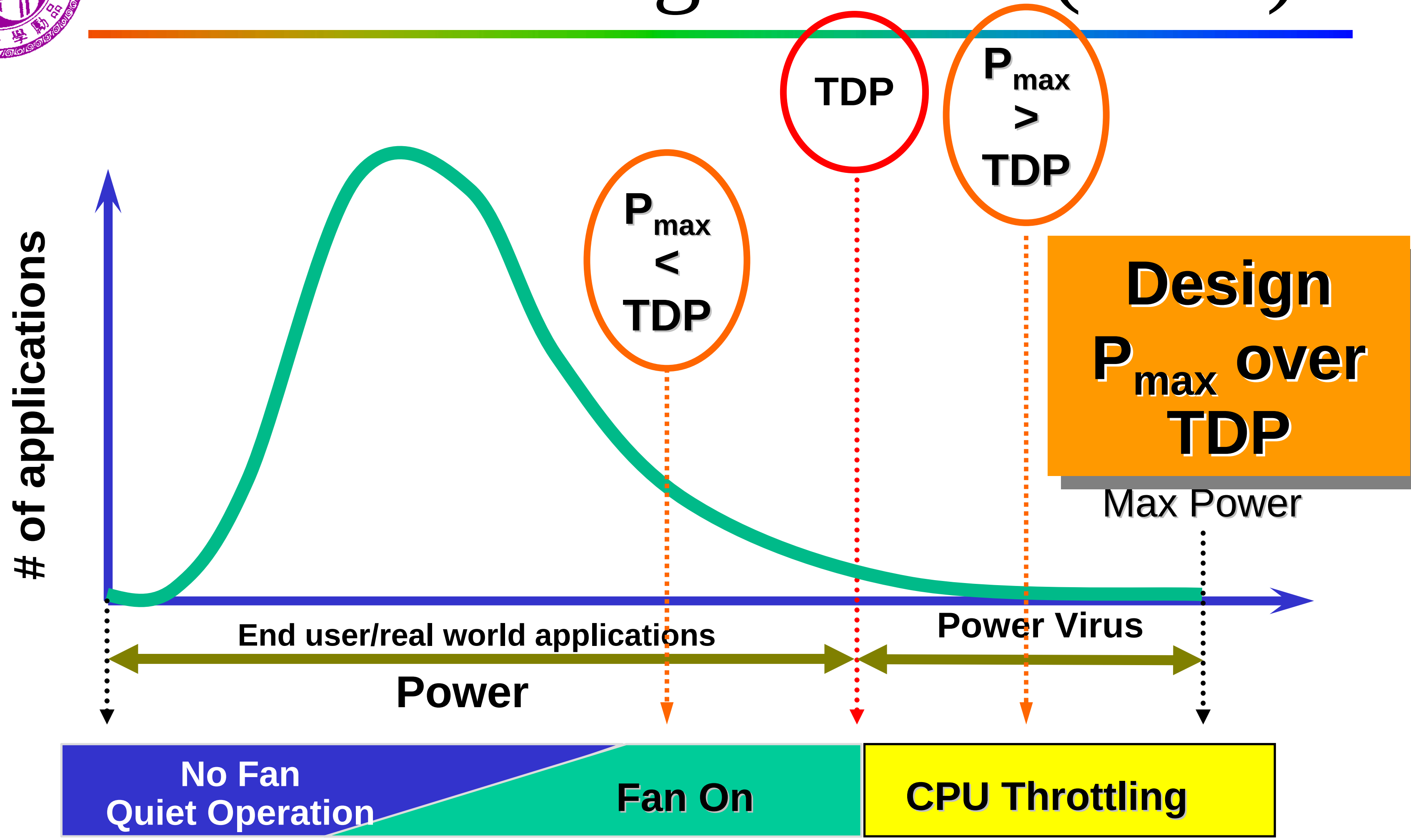
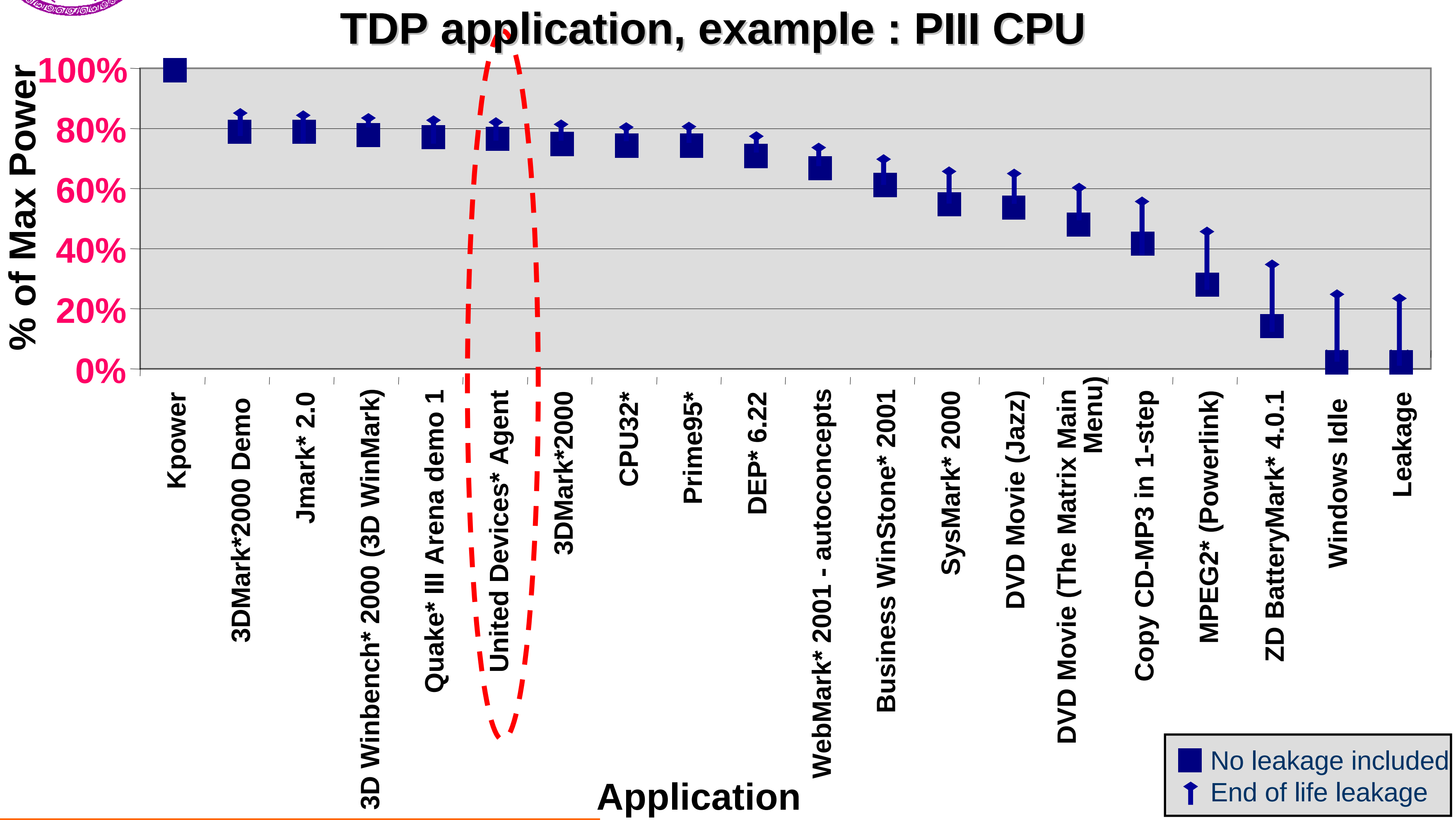
Thermal Design Power (TDP)



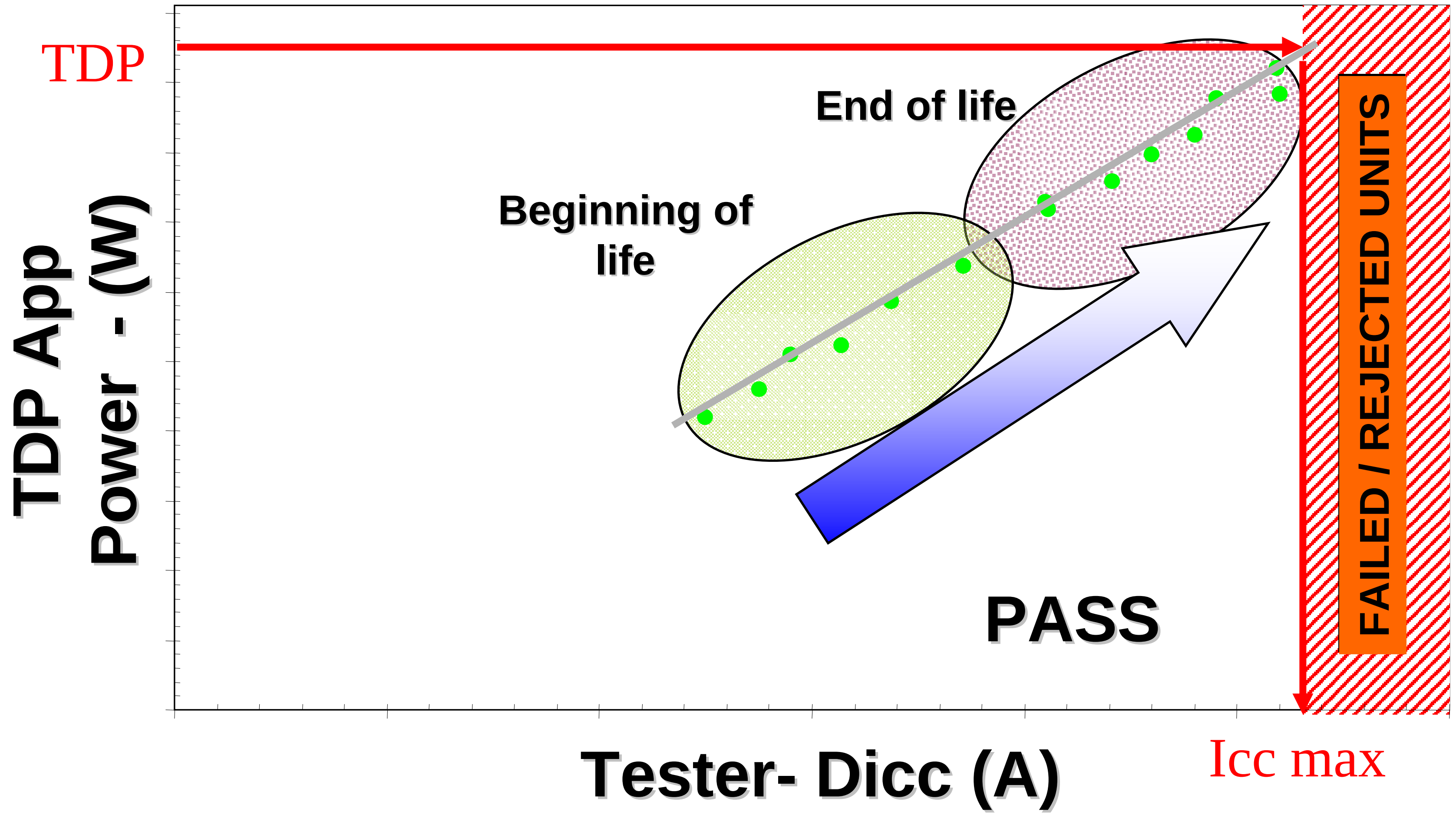
TDP Cover the majority of Real World Applications

Heat generated by CPU



Application Ratio changes with leakage (unit to unit)

TDP_{typ}



TDP
End of life
Beginning of life
TDP App Power - (W)
PASS
FAILED / REJECTED UNITS
Tester- Dicc (A)
Icc max

CPU Power Data

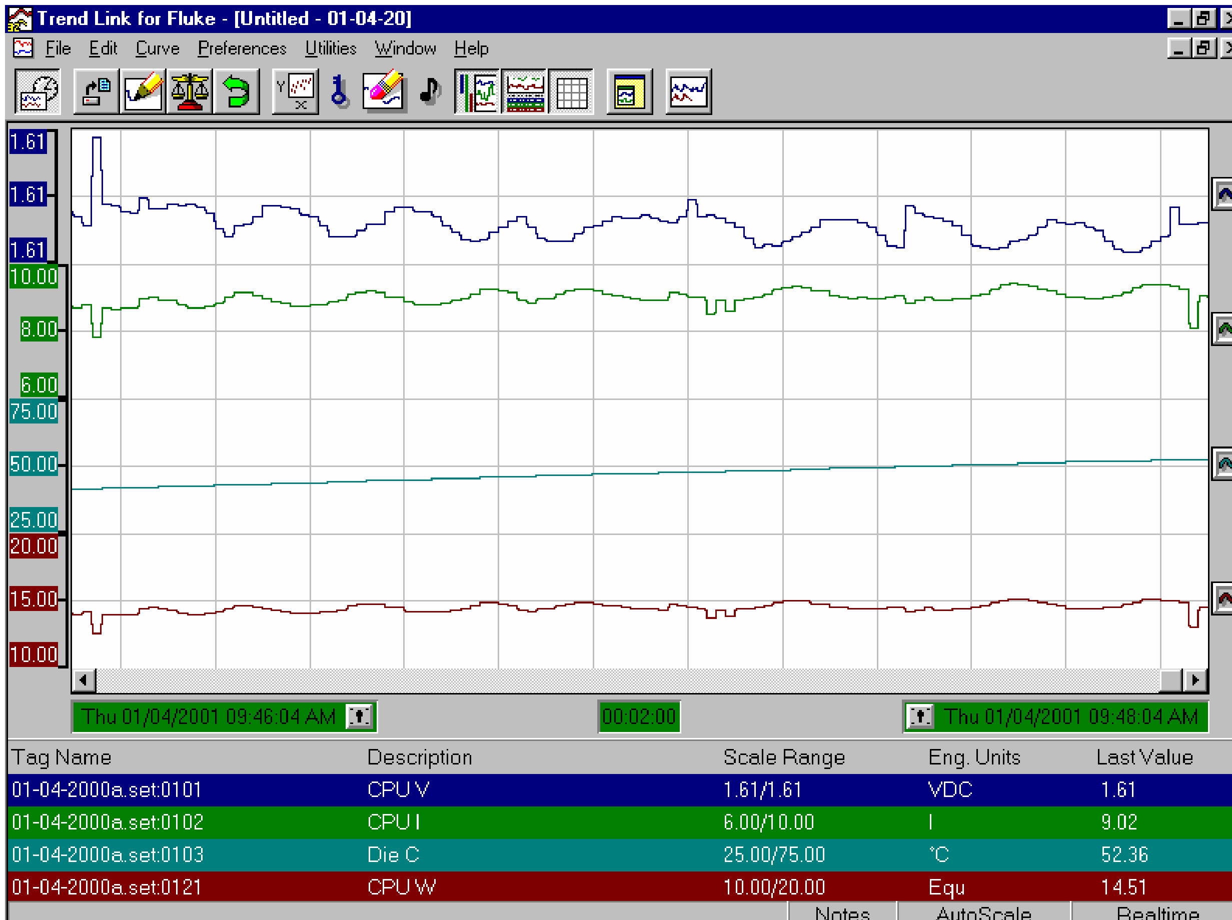
- CPU power data (example)

V_{CPU}

I_{CPU}

T_j (°C)

P_{CPU} (W)



CPU Power Consumption

- Part to part variation
- Lot to lat variation
- Manufacturing process
  - Stepping
- Application

Agenda

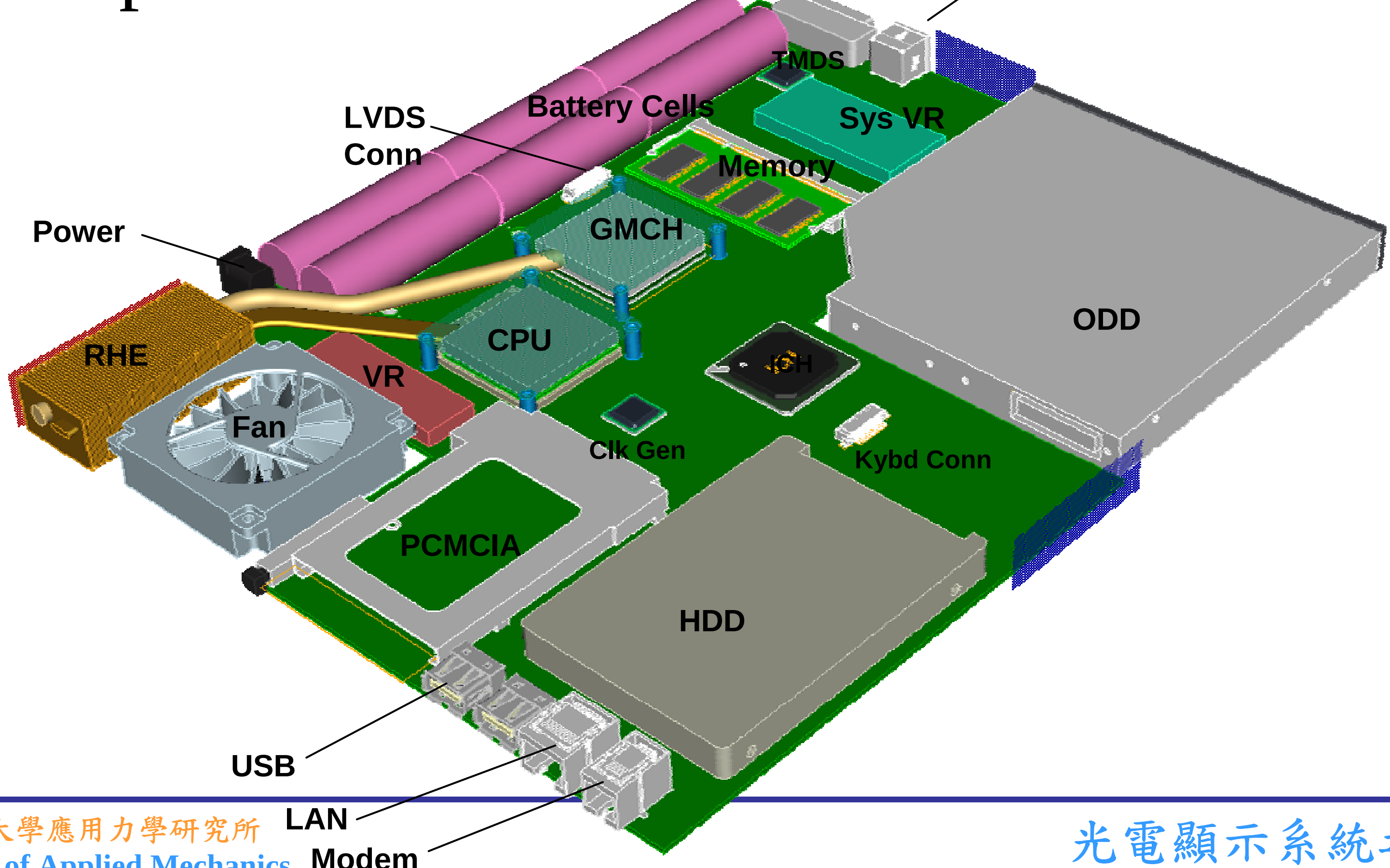
- NB Configuration
- Specification
- Thermal Resistance
- Thermal Design Power
- Thermal Validation & Analysis
- Thermal Management
- Summary

Thermal Validation

- Thermal couple placement
- IR image
- Thermal test environment
- Thermal stress
- CPU power measurement
- System Effect
- CPU contact pressure measurement
- Flow measurement

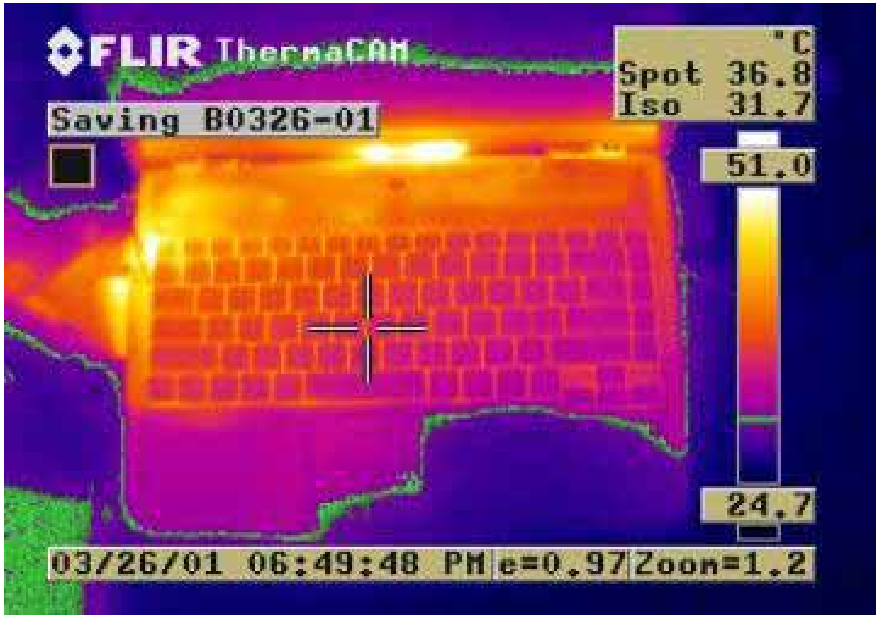
Thermal Couple Placement

- Place thermal couples onto main components

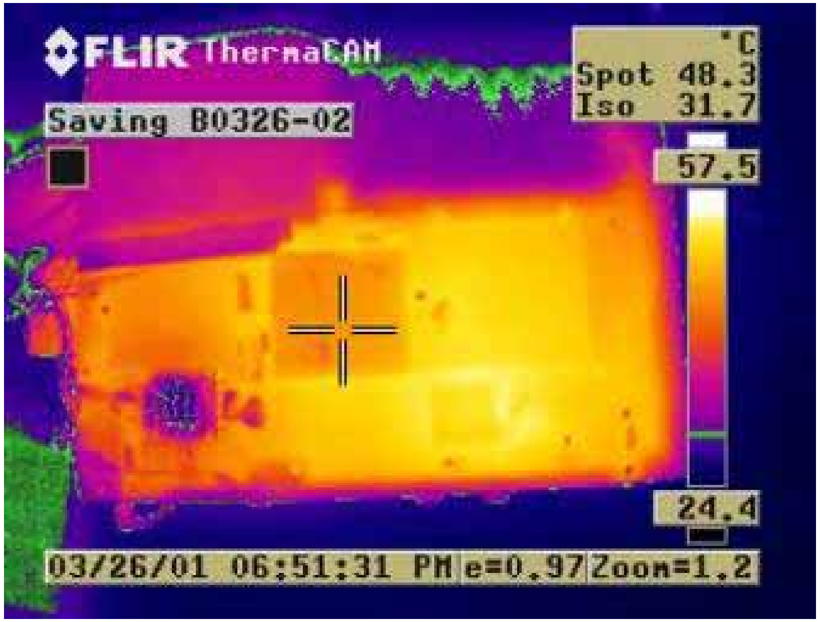


IR Image

- Locate hot spot on skin



Notebook Top Skin



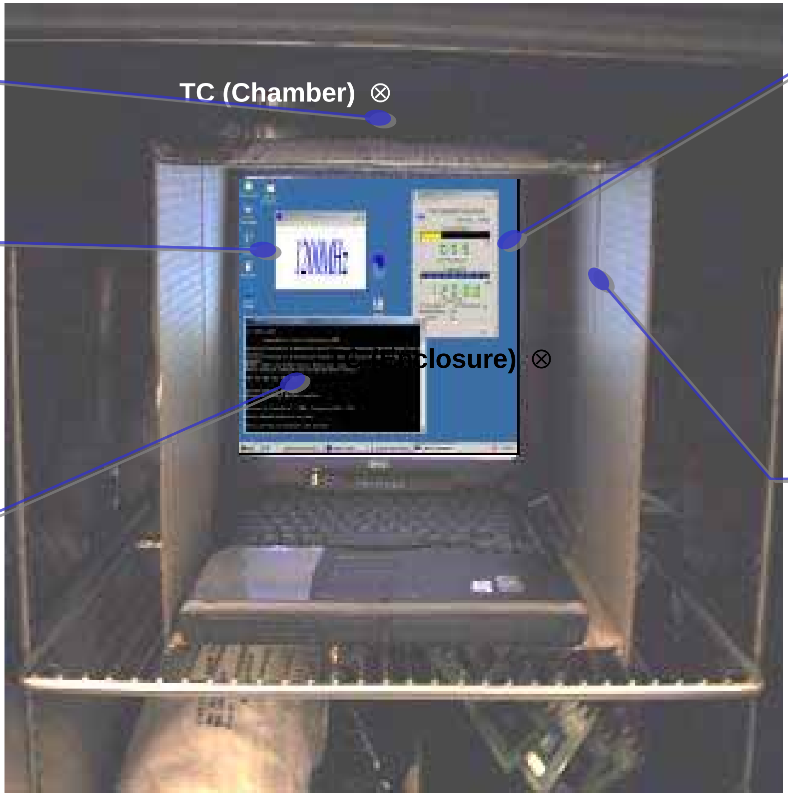
Notebook Bottom Skin

Thermal Test Environment

T_a = 35 ^{o}C

Ensure no throttling

High power application

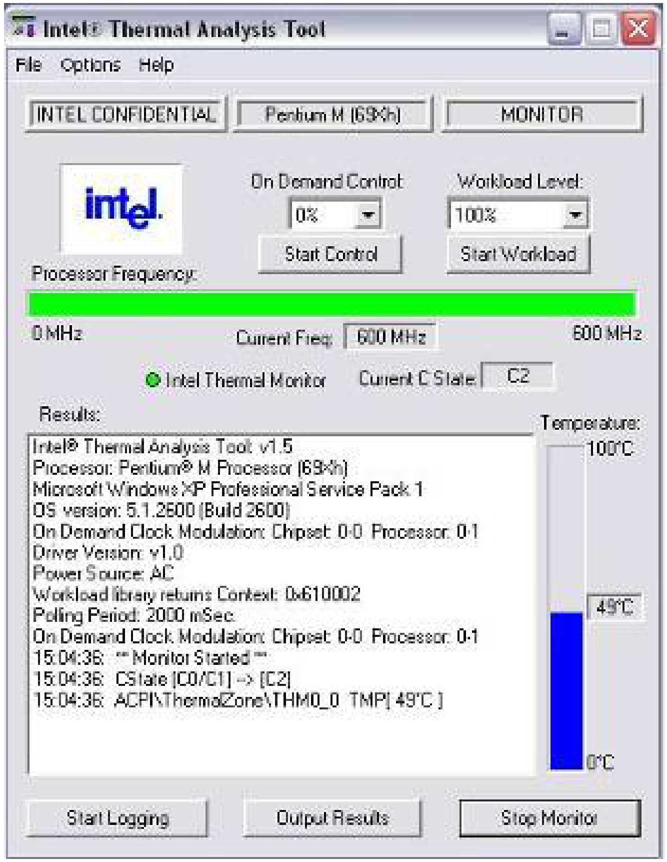


Reading Tj

No air flow over Notebook

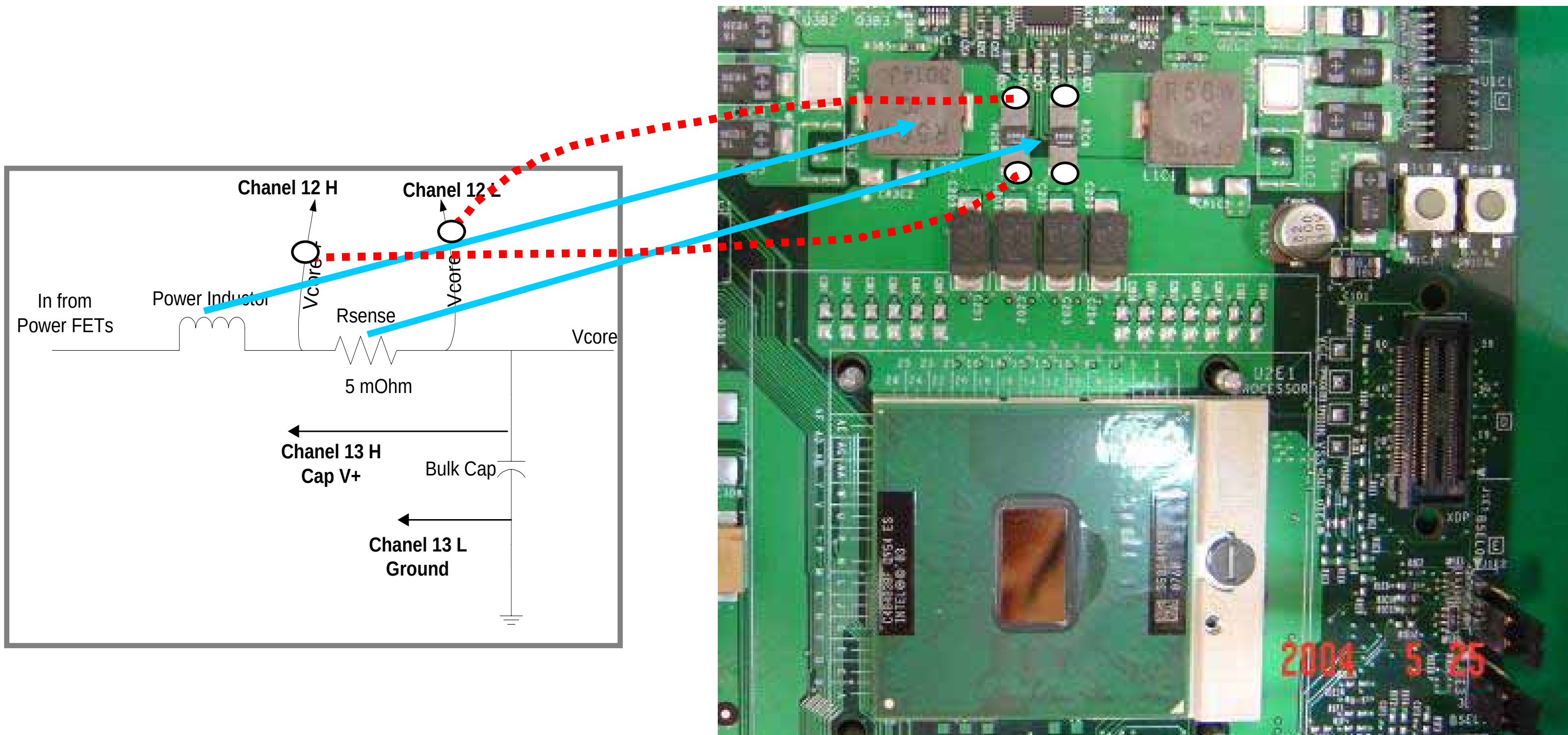
Thermal Stress

- Thermal Analysis Tool (TAT)



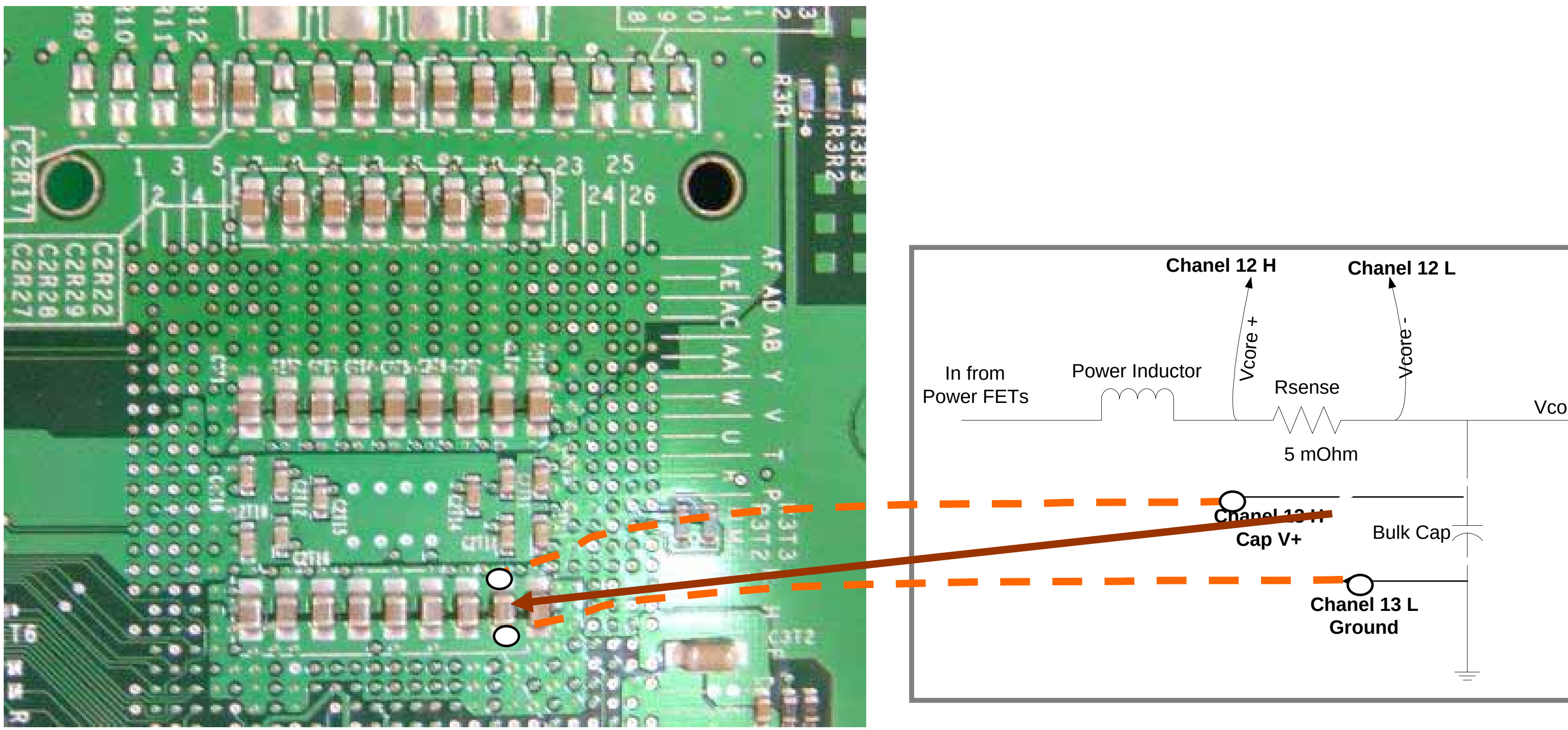
CPU Power measurement

- Measure CPU current



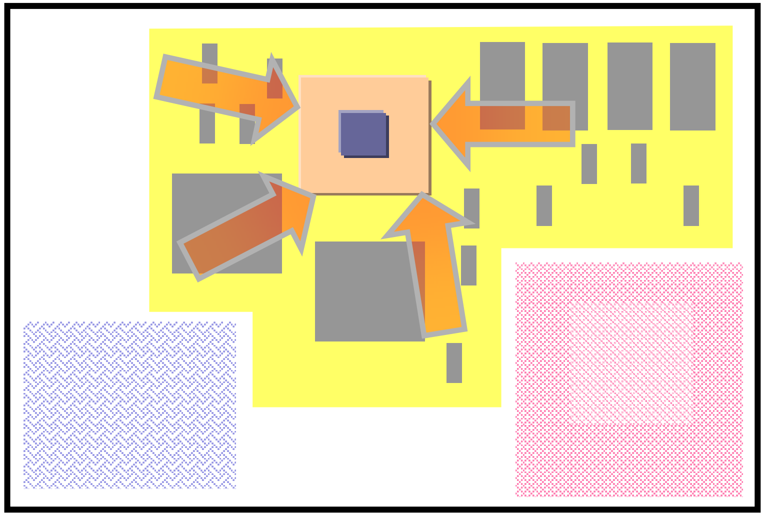
CPU Power measurement

- Measure CPU voltage drop



System Effect

- **Defined as processor junction temperature increase due to system influence (measured as T_{sys})**
  - System effects may be different for each notebook
    - Same thermal solution, different notebook
  - System effects may change from one platform to the next
    - Same notebook and thermal solution, different platform

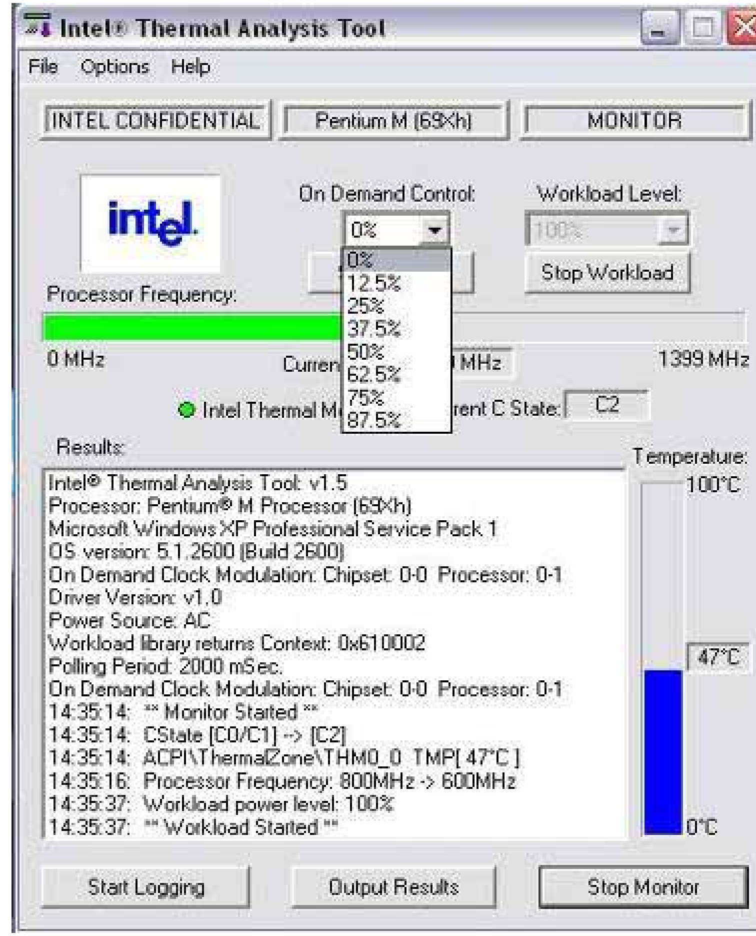


$$\theta_{j-a} = \frac{T_j - T_a - T_{sys}}{P_{cpu}}$$

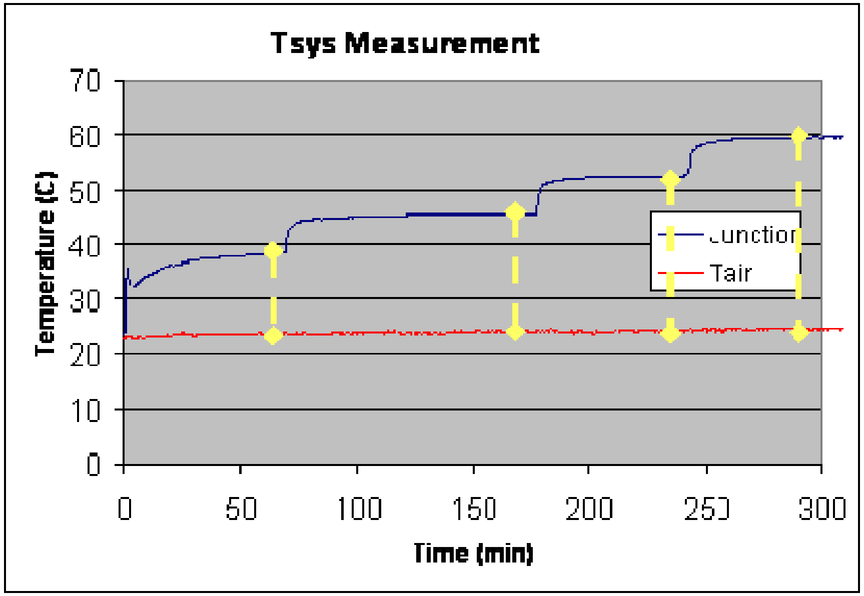
$$P_{max} = \frac{T_{j(max)} - T_{a(max)} - T_{sys}}{\theta_{j-a}}$$

Measurement of T_{sys}

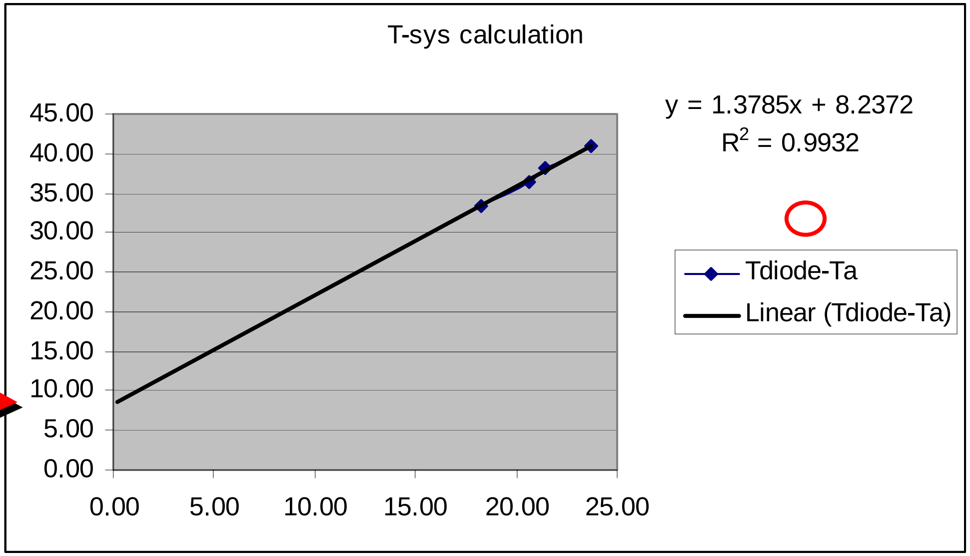
- **Step-by-step instructions**
  - Throttle processor using Thermal Analysis Tool (TAT)
  - Run power level at 100% and change throttle settings to 37.5%, 25%, 12.5% & 0%
  - Measure processor power, and record the diode, ambient temperatures at each step
  - Let each step reach thermal stabilization
  - A trendline through the plot of processor power versus Tj-Ta will reveal T_{sys} and θ_{ja}
- **At extrapolated 0% processor utilization, only T_{sys} will be heating the processor**



T_{sys} Throttling Calculation



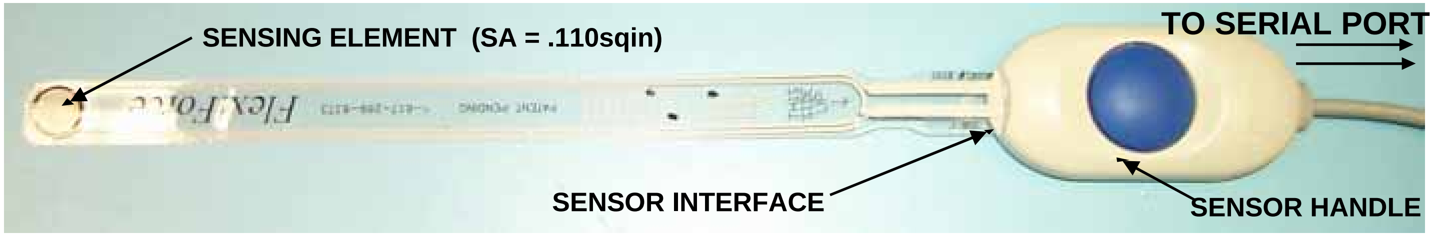
T_{sys} ~ 8 ^{0}C



- Y-intercept from linear trend-line is T_{sys}

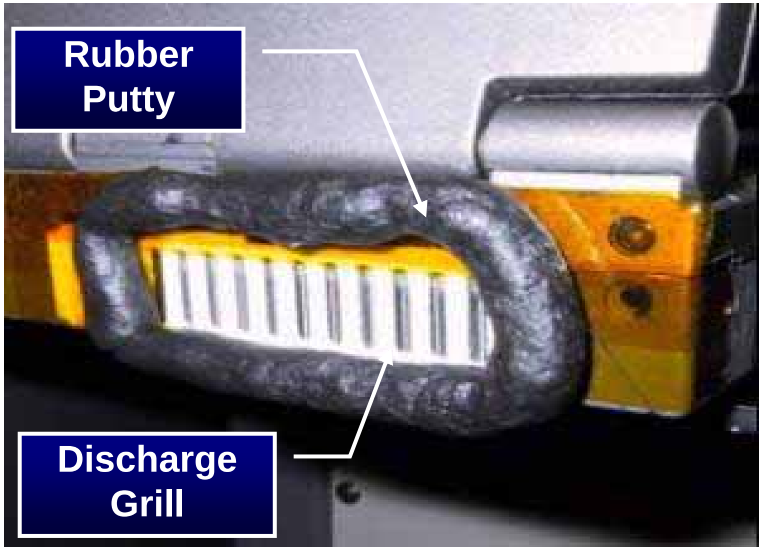
CPU Contact Pressure Measurement

- Main Features
  - The Economical Load Force (ELF) system acts as a variable resistor in a circuit
  - Sensor measures a resistance that is correlated to a load force
  - Active sensing area (SA = .110sqin) measures the applied load
    - Sensors are available in different sizes and force ranges

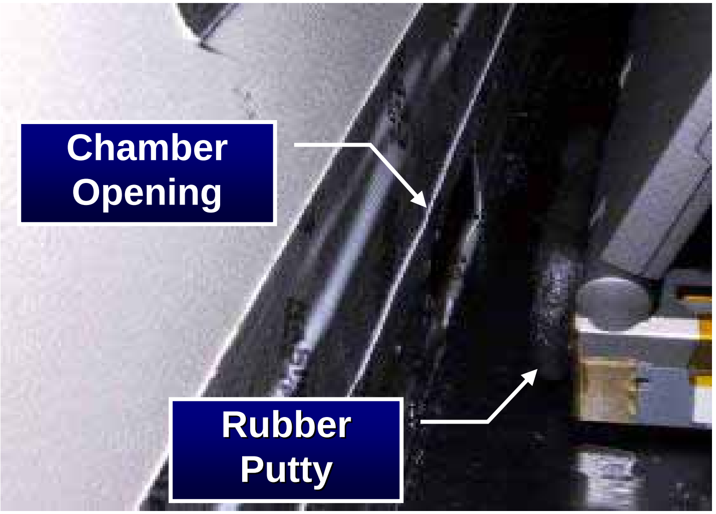


Flow Measurement

- System flow resistance measurement



Use of rubber putty to create a seal



Alignment of the fan discharge against the flow chamber

Fan Testing (Blower)

- Use installed condition fan performance (plate over inlet)

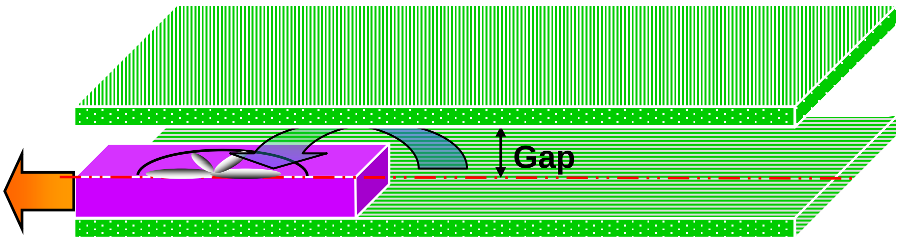
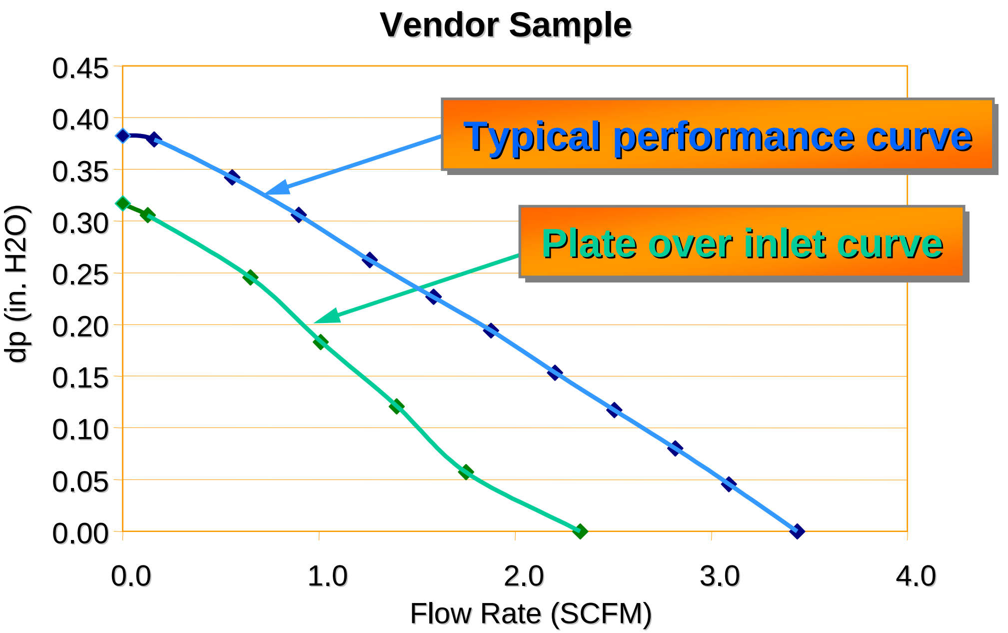
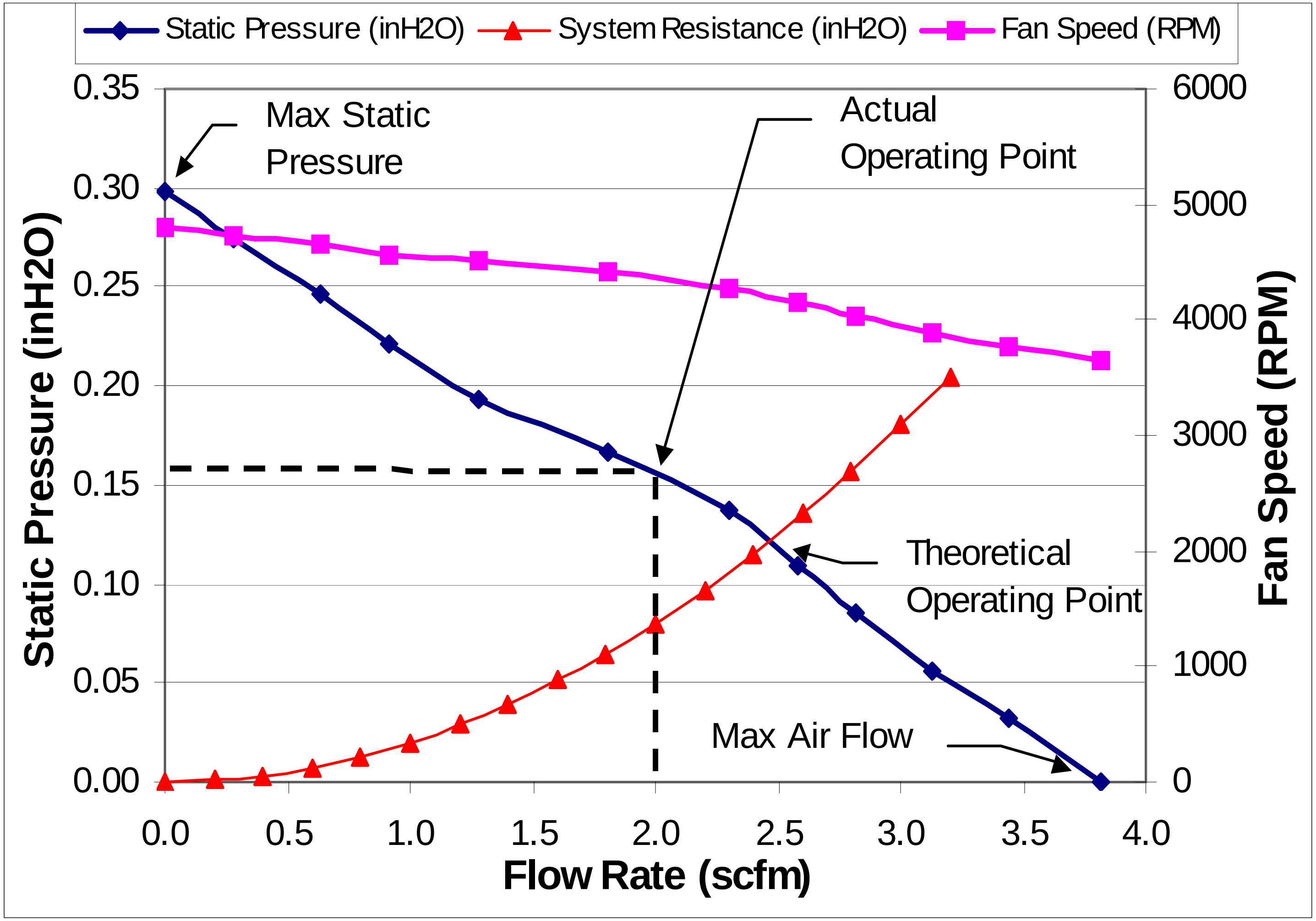


Plate at "z" over inlet
(simulates installed conditions)



Need to get installed condition fan curve

P-Q curve & Thermal Resistance



Data Analysis

- Thermal resistance & thermal capability
  - θ_{ja} vs. P_{max}

θ_{ja} vs. P_{max}

- Thermal resistance

$$\theta_{ja} = \frac{\left(T_j - T_a - T_{sys}\right)}{P_{CPU}} \qquad \theta_{ca} = \frac{\left(T_c - T_a - T_{sys}\right)}{P_{CPU}}$$

- Thermal capability

$$P_{\max} = \frac{\left(100^o C - 35^o C - T_{sys}\right)}{\theta_{CA}} \qquad P_{\max} = \frac{\left(70^o C - 35^o C - T_{sys}\right)}{\theta_{CA}}$$

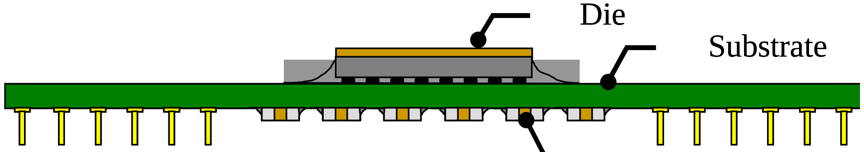
- TDP_{typ} vs. P_{max} / θ_{ca} vs. Θ_{ca} spec.

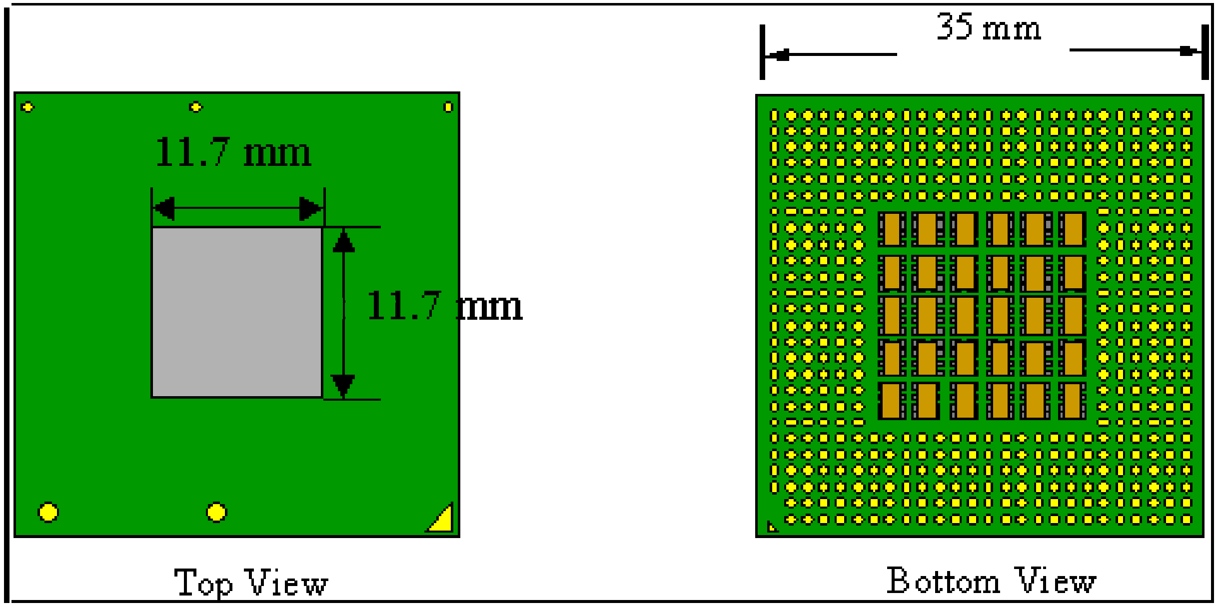
$$P_{\max} \geq T_{TDP_{typ}} \qquad \theta_{ca} < \Theta_{ca_{spec.}}$$

Thermal Test Vehicle

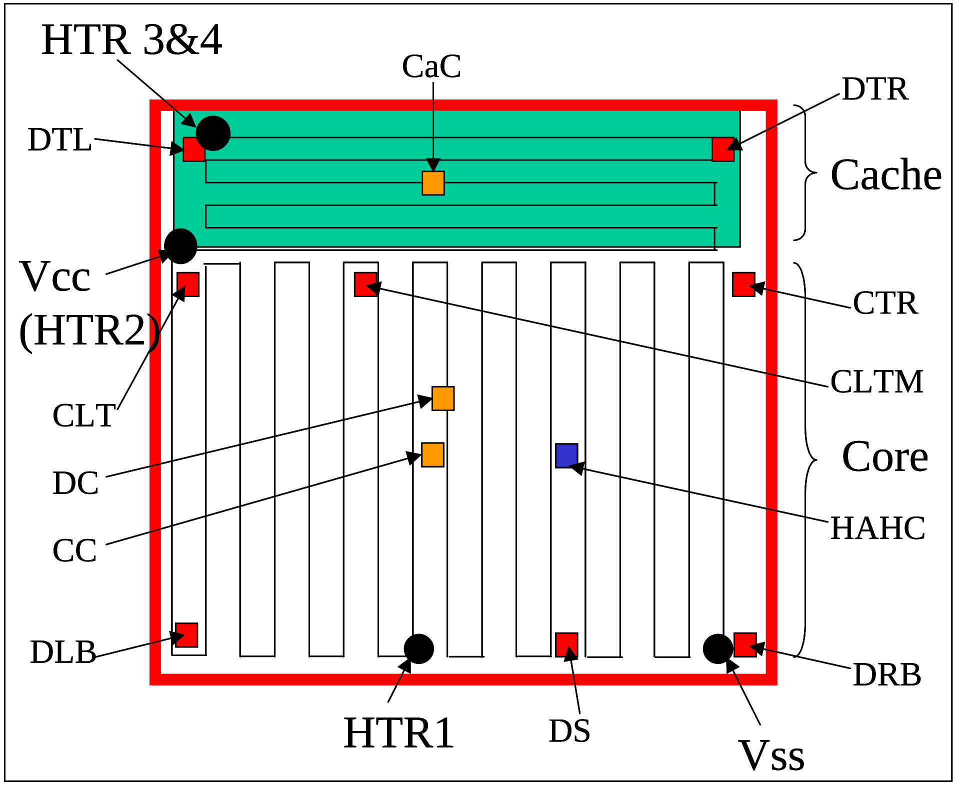
- CPU thermal vehicle
  - Tualatin thermal vehicle (TTV)
  - Northwood thermal vehicle (NTV)
  - Banias thermal vehicle (BTV)
- Chipset thermal vehicle
  - Almado thermal vehicle
  - Brookdale thermal vehicle

P4-m Thermal Vehicle

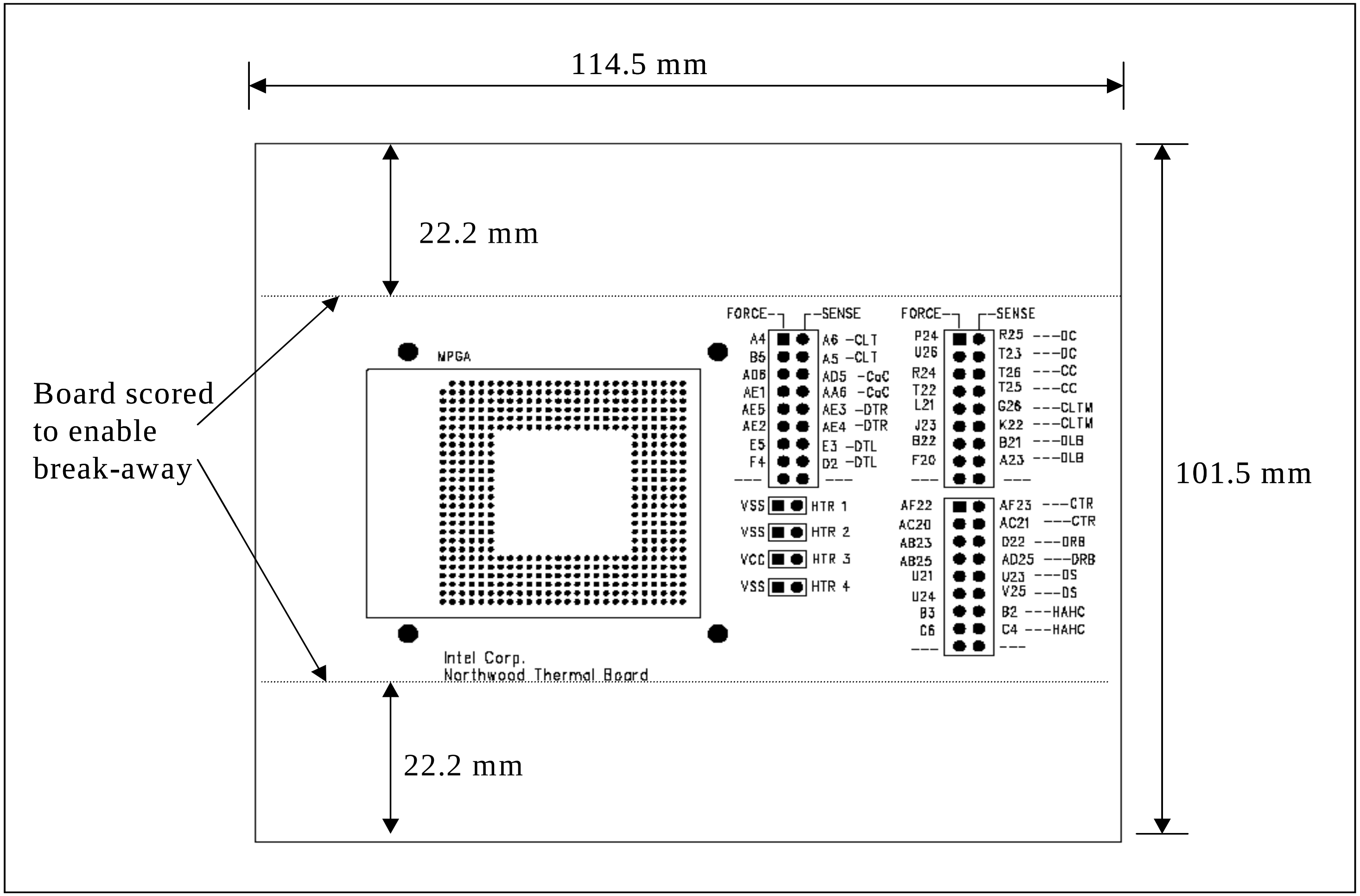




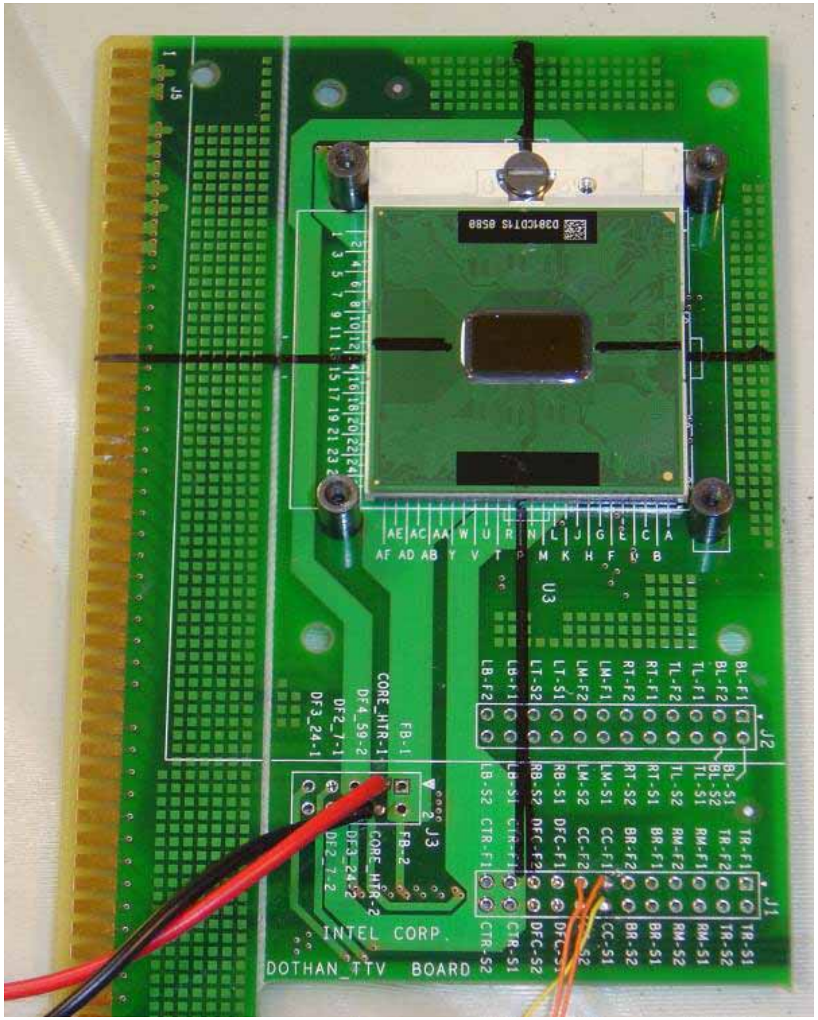
P4-m Thermal Vehicle



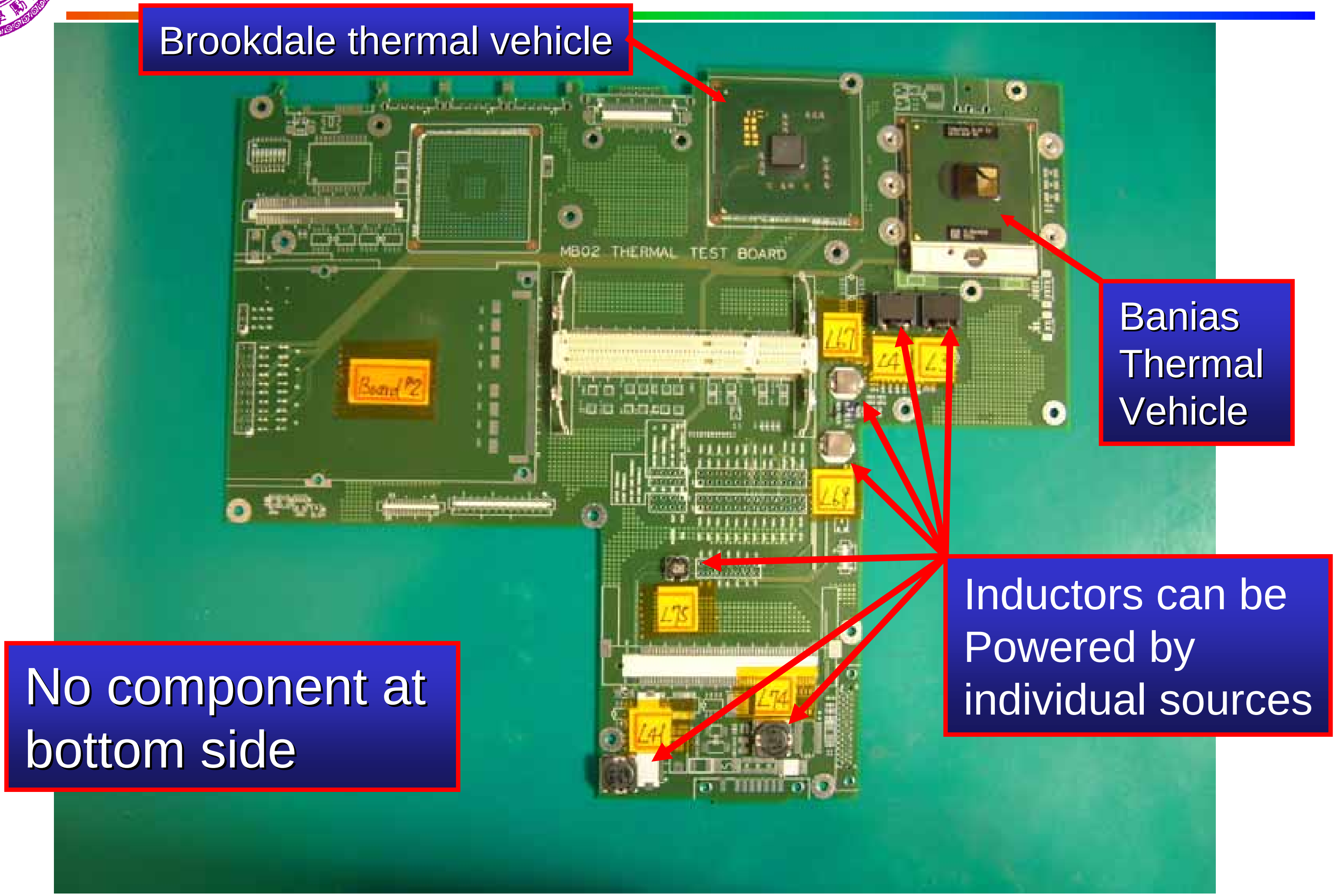
P4-m Thermal Vehicle



Thermal test vehicle (TTV)



Thermal Board Example



Thermal Board Example

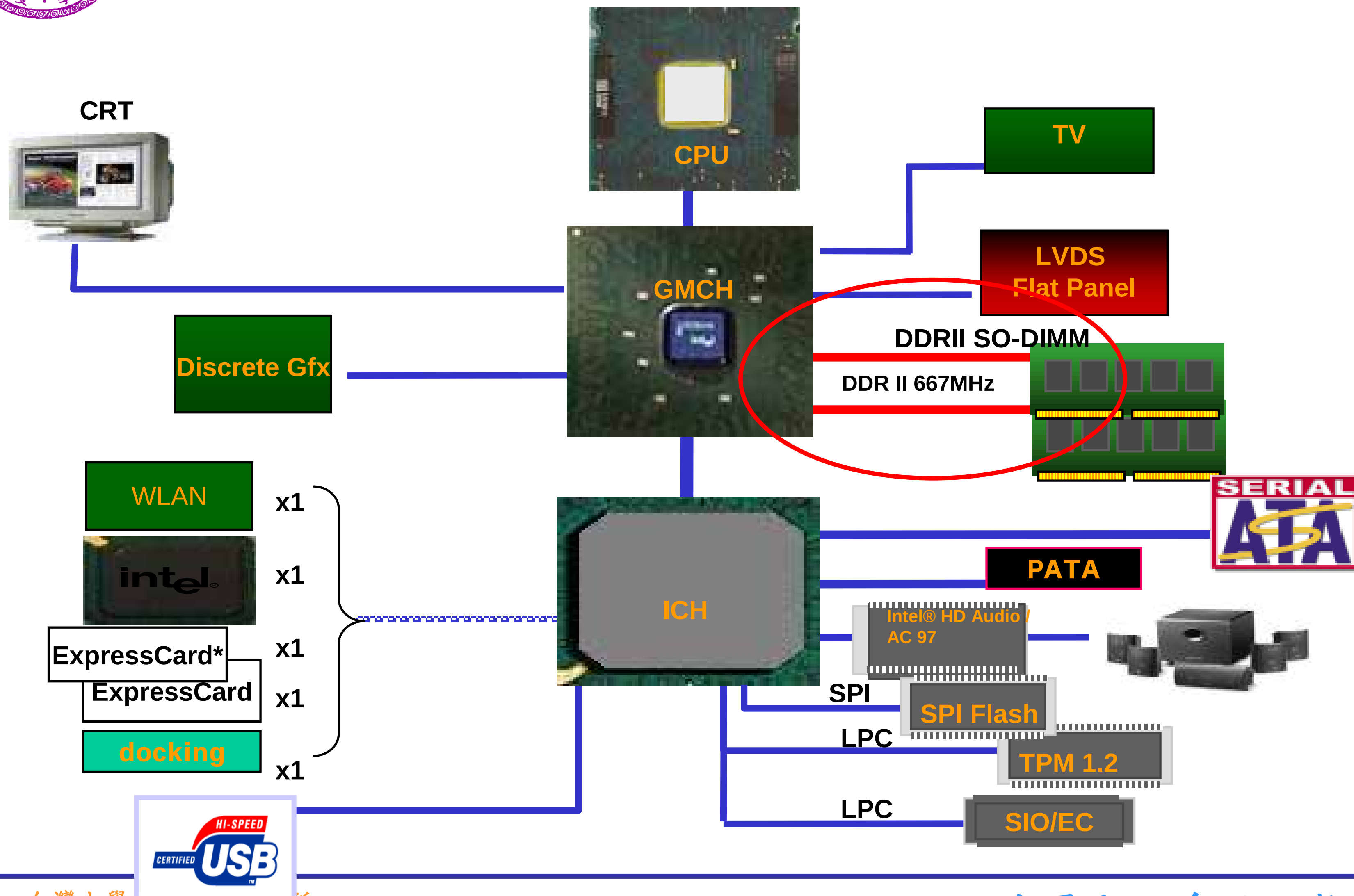
Agenda

- NB Configuration
- Specification
- Thermal Resistance
- Thermal Design Power
- Thermal Validation & Analysis
- Thermal Management
- Summary

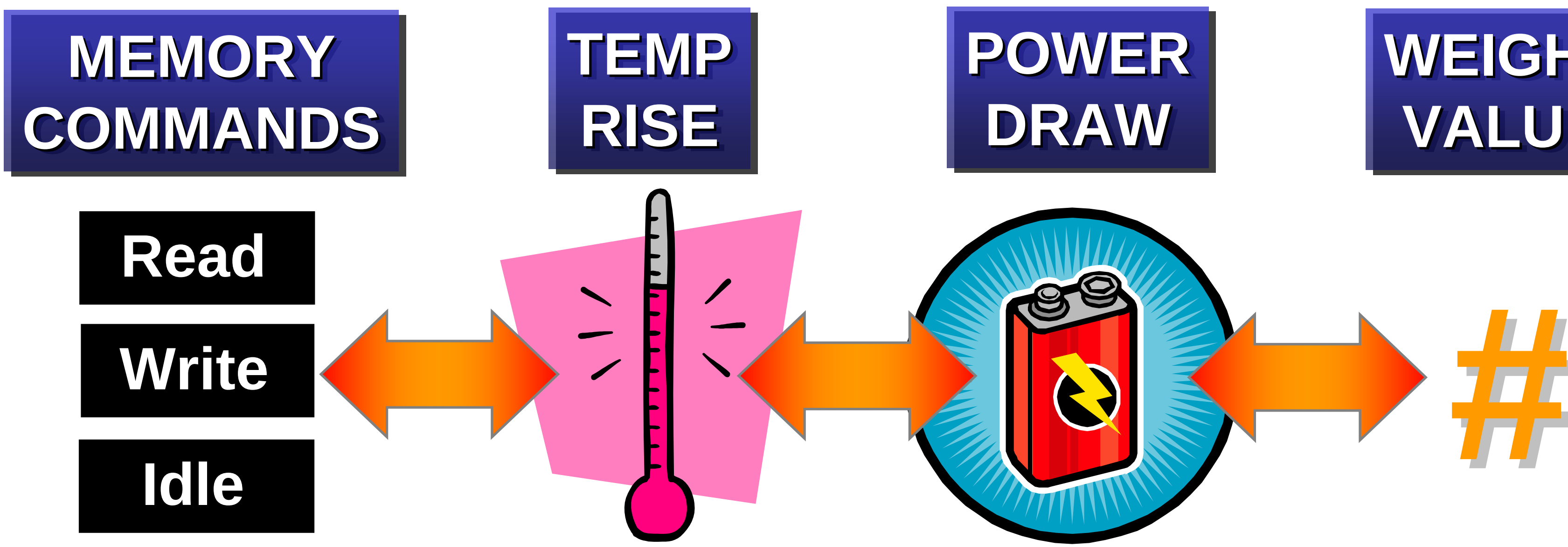
Thermal Management

- Weight vs. DT
- Throttling
- Thermal sensor
- Fan speed control

NB Configuration



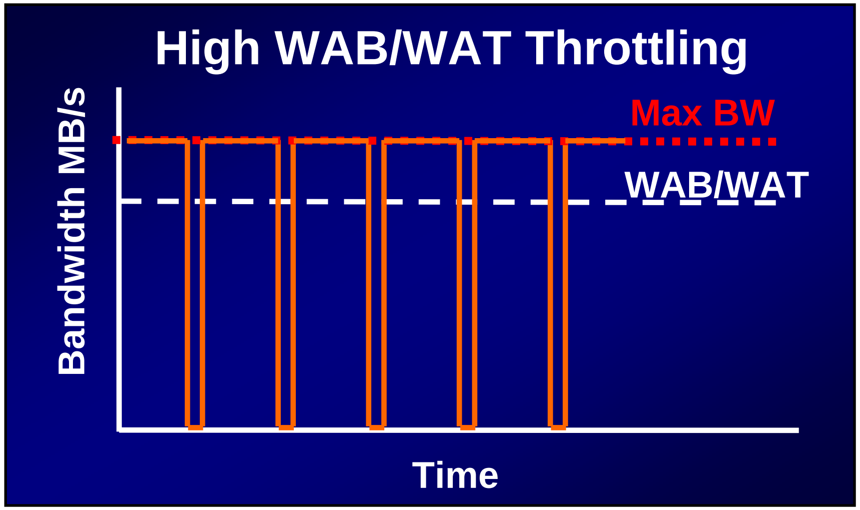
Delta Temperature (DT)

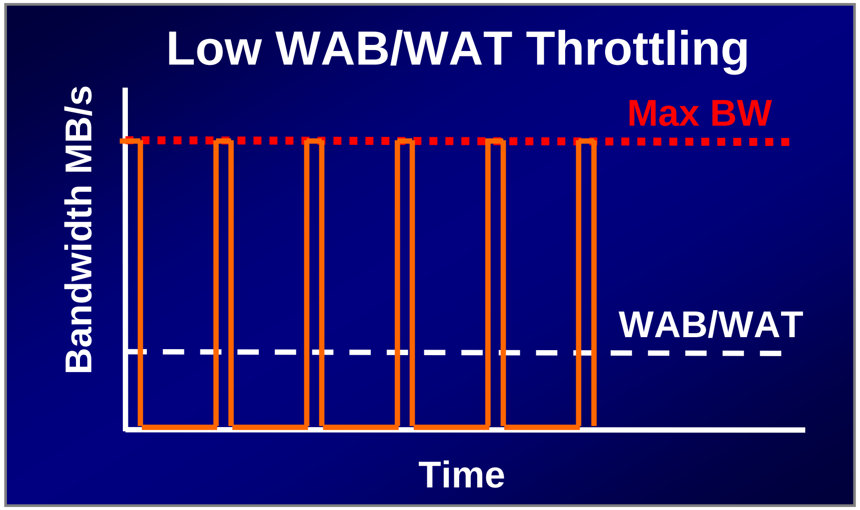


- Temperature rise due to specific memory commands on a memory component
- Temp rise is related to power draw
- Power draw is interpreted into “weights”

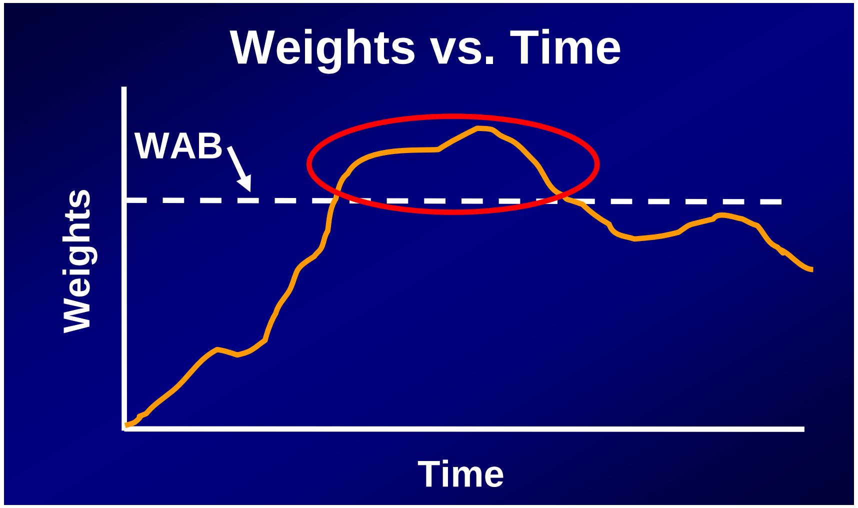
Throttling

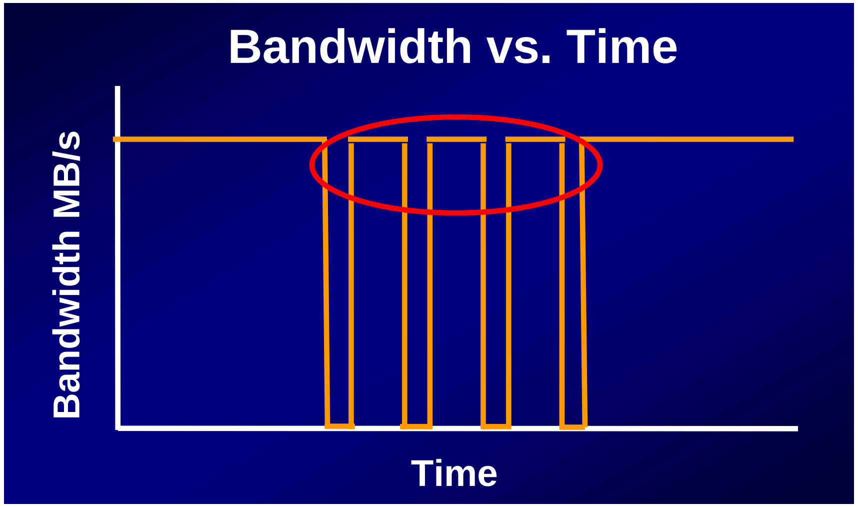
- Chipset & Memory throttling



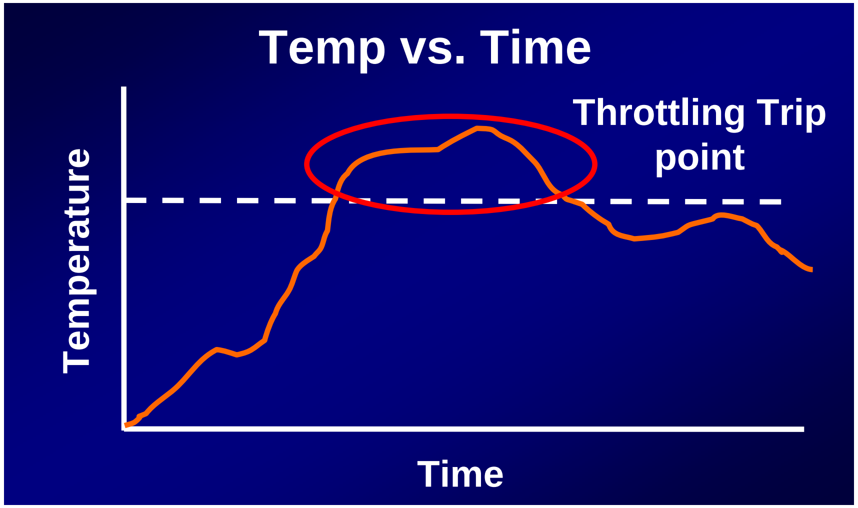


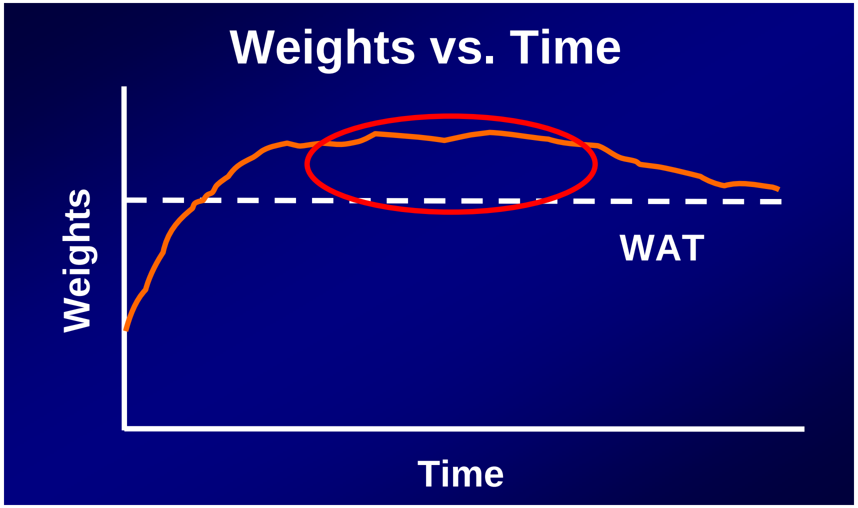
Weighted Average Filter – Bandwidth (WAB)

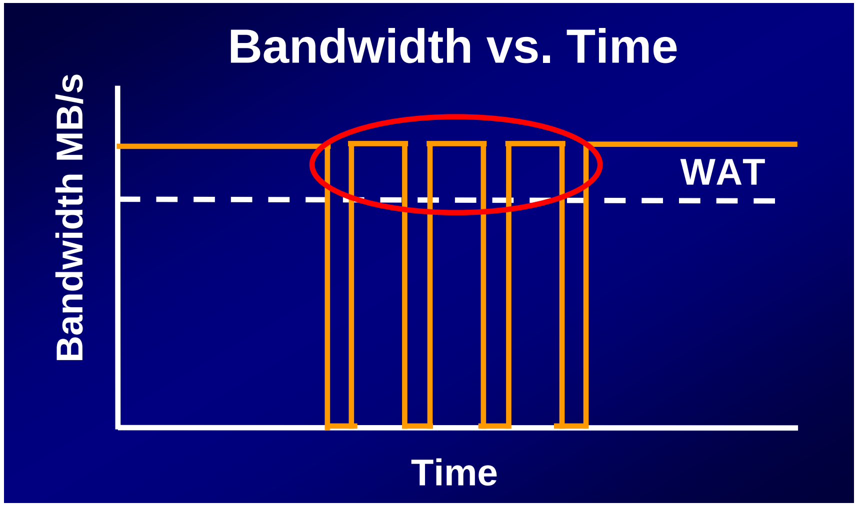




Weighted Average Filter – Temperature (WAT)

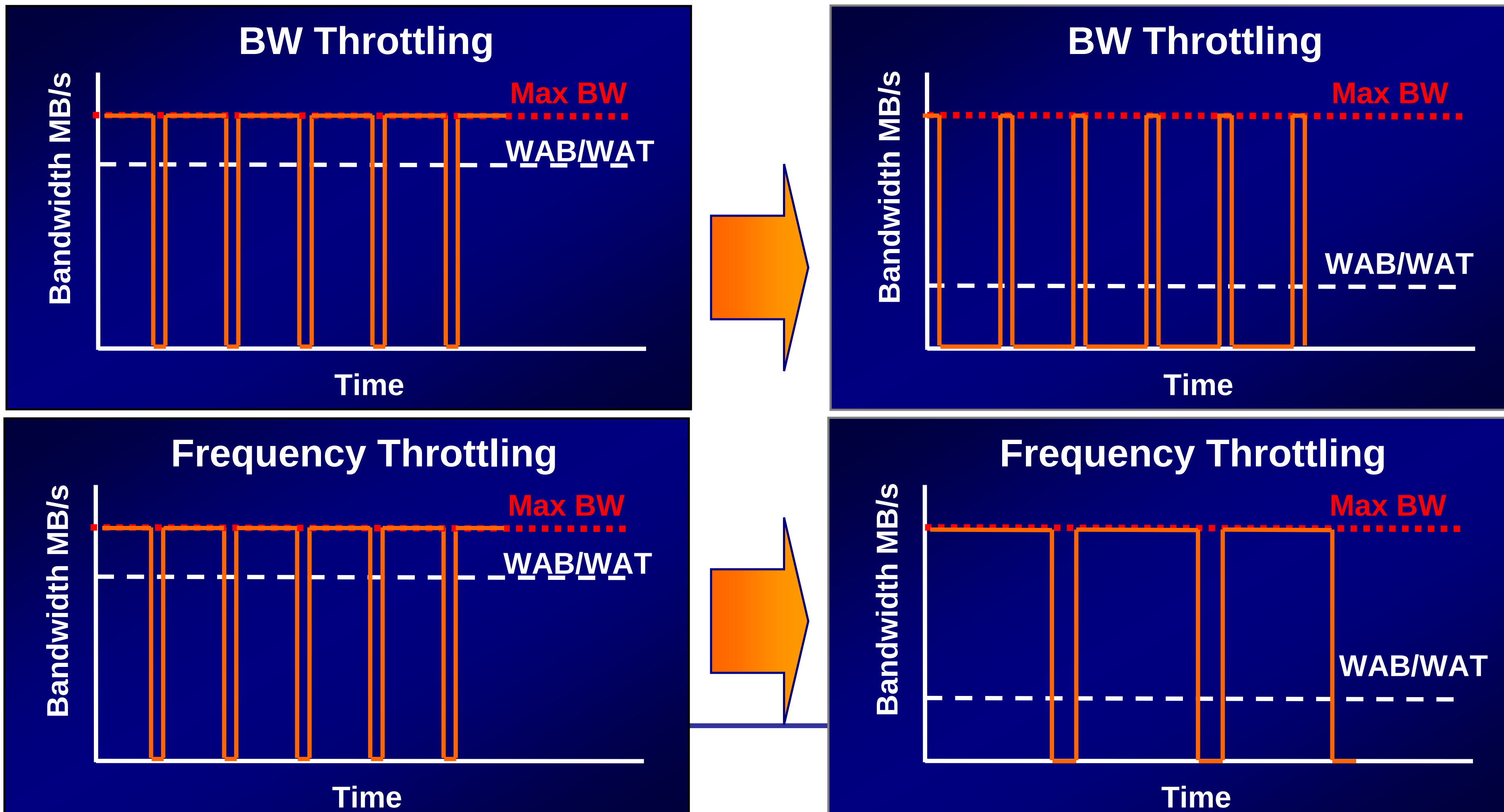






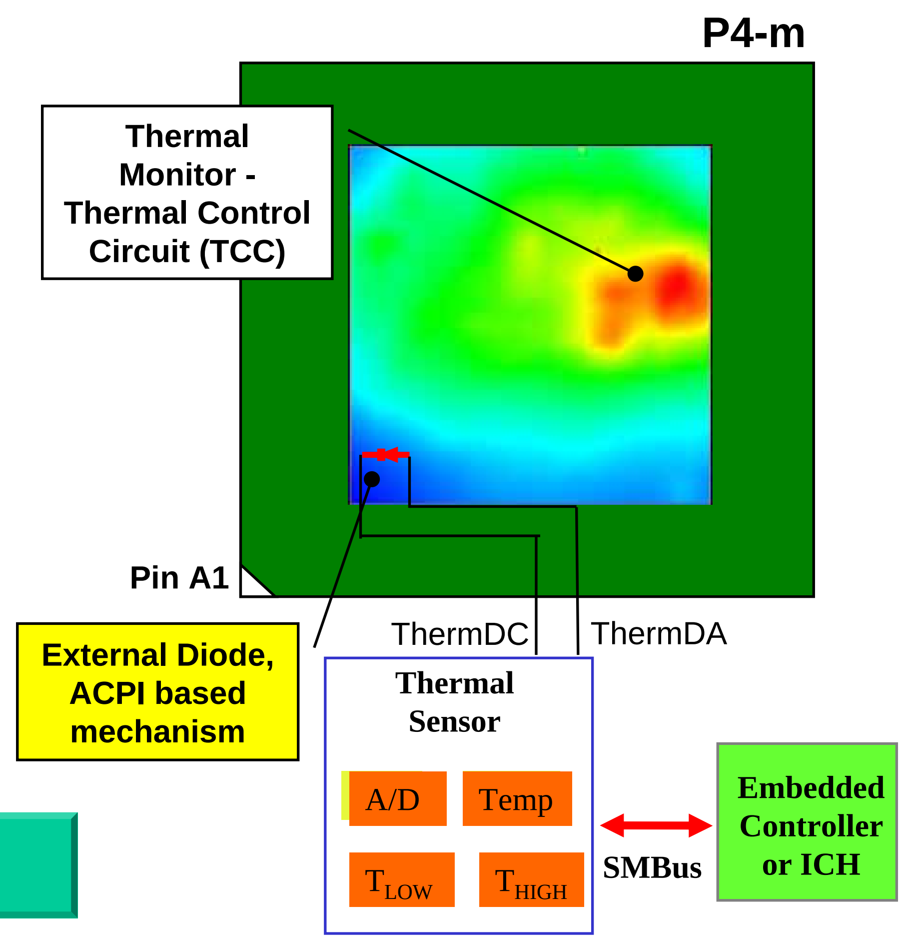
Throttling

- CPU throttling

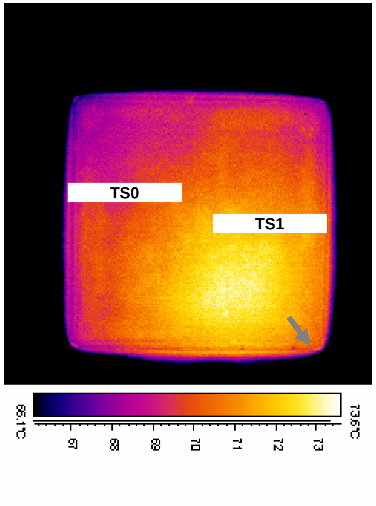


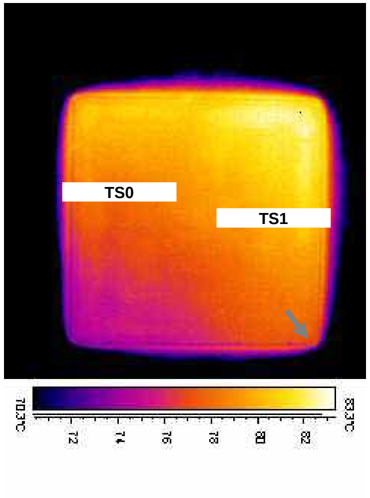
Thermal monitor & Diode

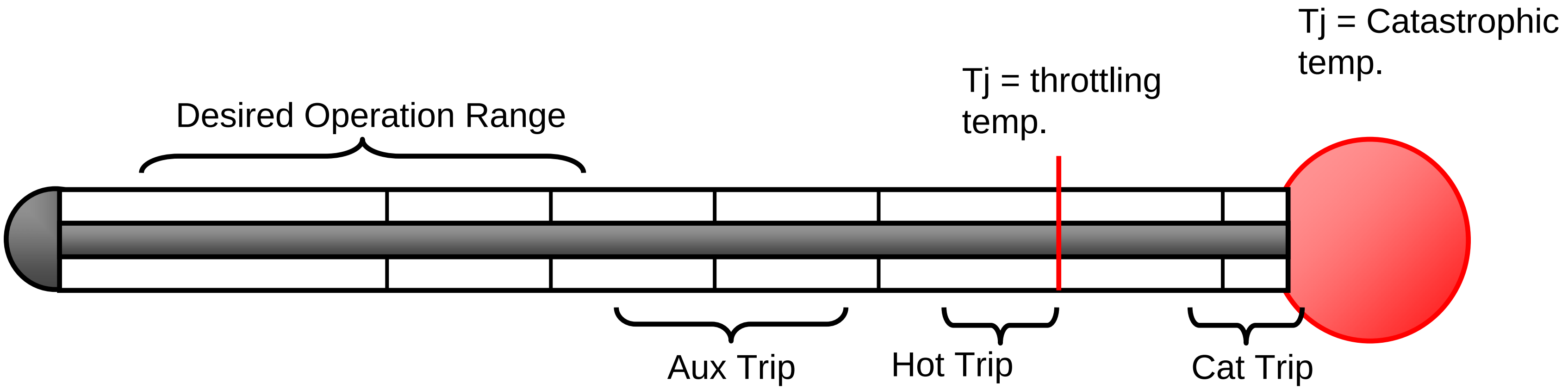
- Thermal Monitor is Intel's name for on-die thermal management
  - On-die Thermal Control Circuit (TCC set at 100 °C) automatically engages throttling located at die hotspot
- Diode
  - On-die diode with off-chip A/D
  - Not located at hottest part of die
- Diode reading Demo



Digital Thermal Sensors (DTS)







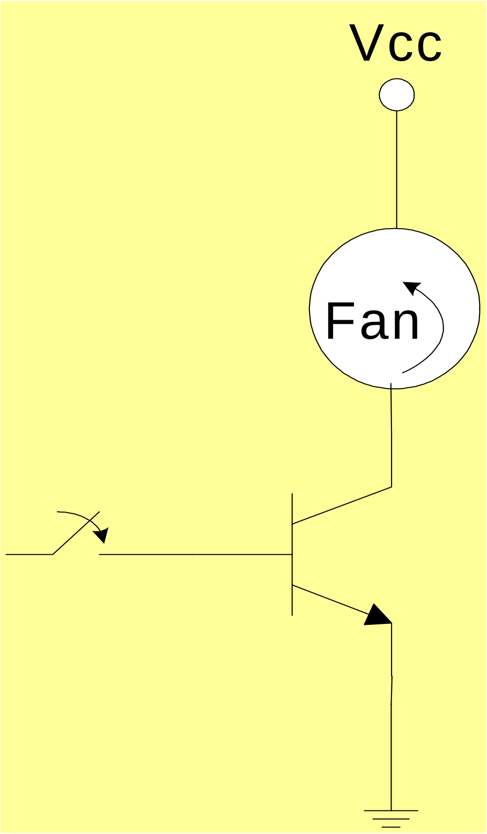
DT (Delta Temperature) in SPD

- SO-DIMM Technology that allows BIOS to read power specification information from the SPD (Serial Presence Detect) and adjust throttling thresholds (weights)
- By using DT in SPD throttle weight registers in the MCH will be programmed with weights computed from the SO-DIMM specific information at boot time
- JEDEC Standard

Thermal Sensor (TS) in SPD

- SO-DIMM Technology integrating a thermal sensor onto the SO-DIMM SPD. TS is used to signal MCH when temperature is hot.
- Information characterizing relationship between TS and DRAM T-case is included in the SPD. The MCH can use this information to program the On-SO-DIMM TS and decide when to throttle memory.
- JEDEC Standard

Speed Control Structure (3 Pins)



Use ON/OFF control by Transistor

Advantage：

I. Easy design and control method

II. Price cheaper.

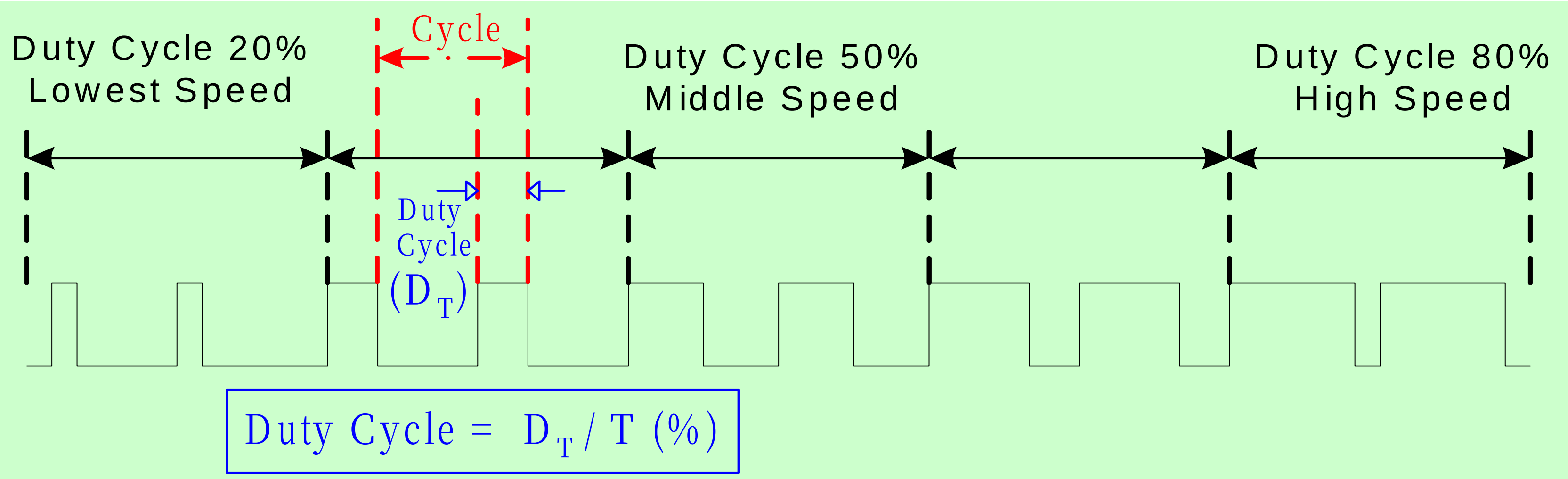
Disadvantage :

I. Power Dissipation is a design issue.

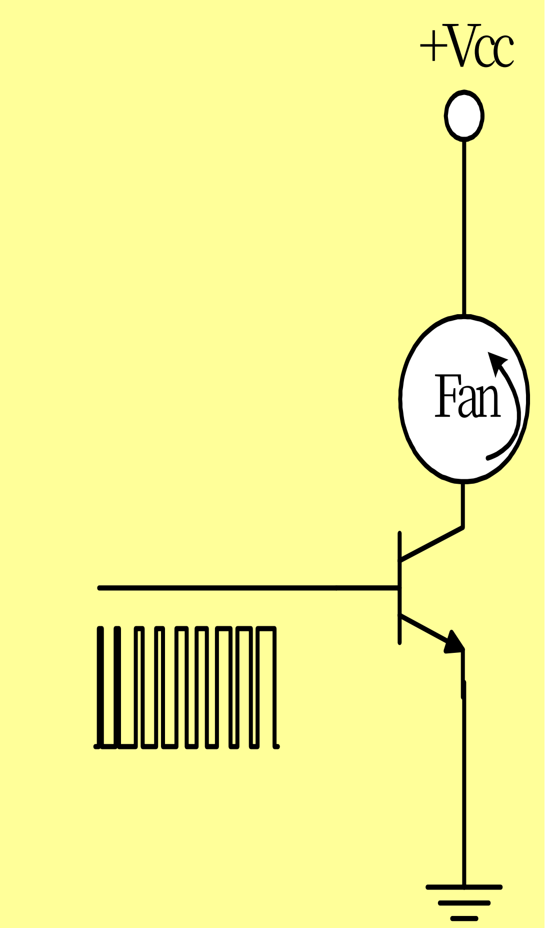
II. Not use friendly.

PWM control

- **PWM(Pulse Width Modulation)**
  - fixed frequency and pulse modulated for fan speed control.
- The Purpose
  - Lower power dissipation



PWM Speed Control Structure (4 Pins)



- **Use ON/OFF control by Transistor**

Advantage：

I. **Easy design and control method**

II. **Price cheaper.**

Disadvantage：

I. **Poor Reliability (Transistor are On/OFF continuously)**

II. **Error judgment of tachometer signal.**

Summary

- E/E structure then NB ME Layout
- RHE & Thermal resistance
- NB thermal validation
  - Thermal test vehicle
- NB thermal management

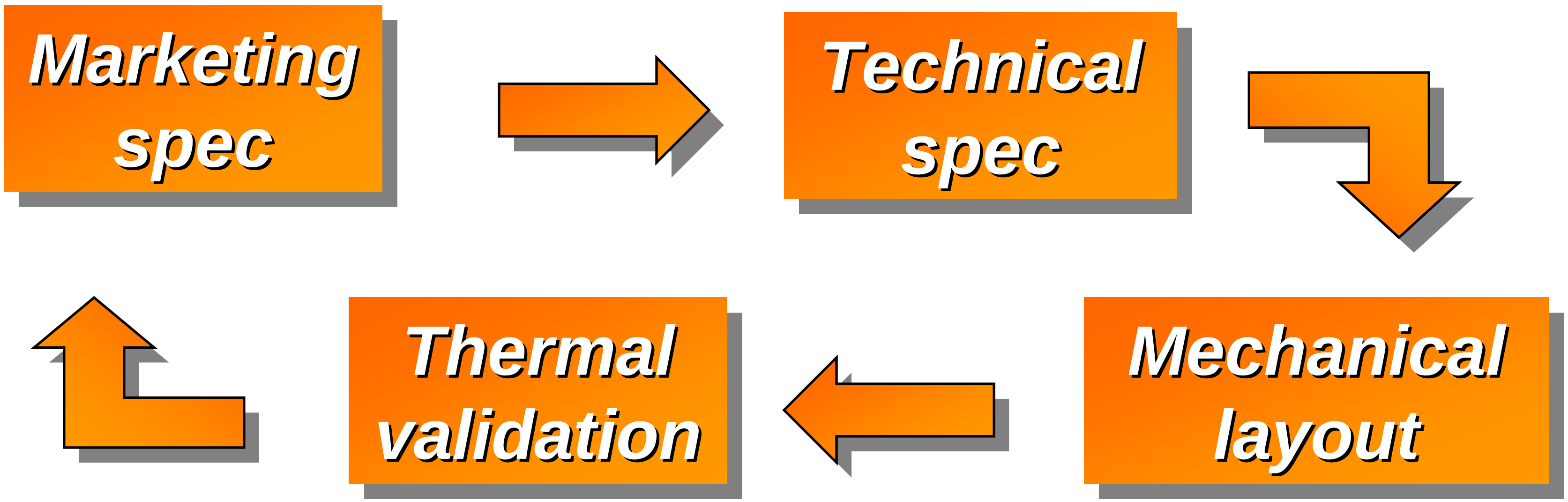
Reference

- Eric DiStefano, Himanshu Pokharna, and Sridhar V. Machiroutu, “Raising the bar for heat pipes in notebook cooling”, 13th International Heat Pipe Conference (13th IHPC), Shanghai, China, September 21-25, 2004.
- Sridhar Machiroutu, Himanshu Pokharna, Eric DiStefano and Ravi Prasher, “Using thermal interface materials in notebook design : challenges in testing and selection”, Whit Paper, Intel Developer Forum (IDF) 2004.

Backup

Thermal Design

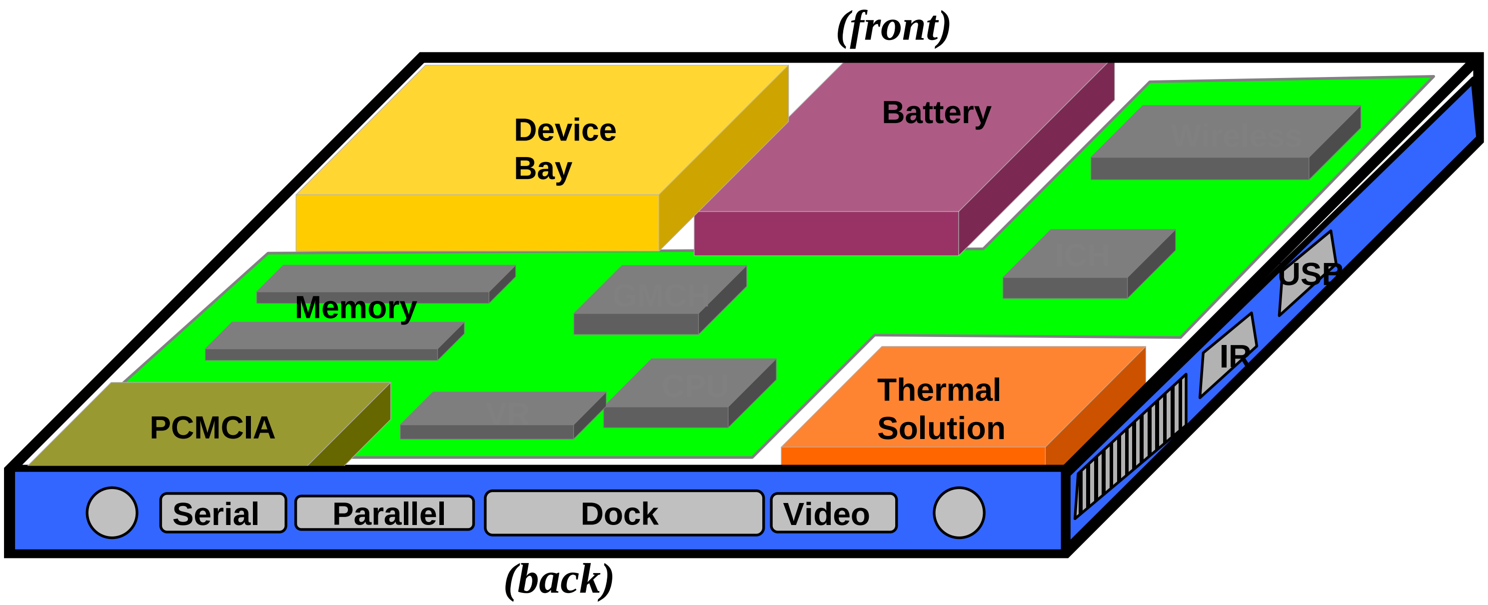
- Notebook PC thermal design process



- The purpose of thermal validation is to ensure the thermal design meet thermal spec.

What's the Notebook thermal spec ?

Mechanical layout



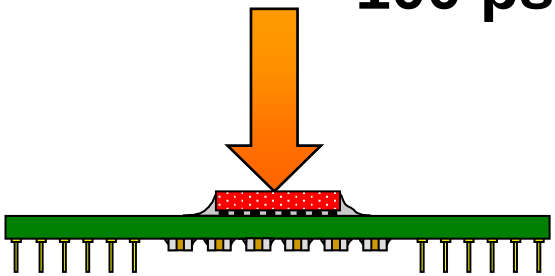
- Mechanical engineer needs to place components by experience

- Integrated Heat Spreader (IHS)

Mobile CPU Package

Micro-FCPGA

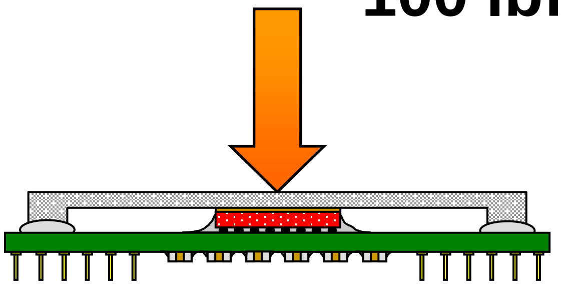
100 psi



Desktop CPU Package

With IHS (FCPGA2)

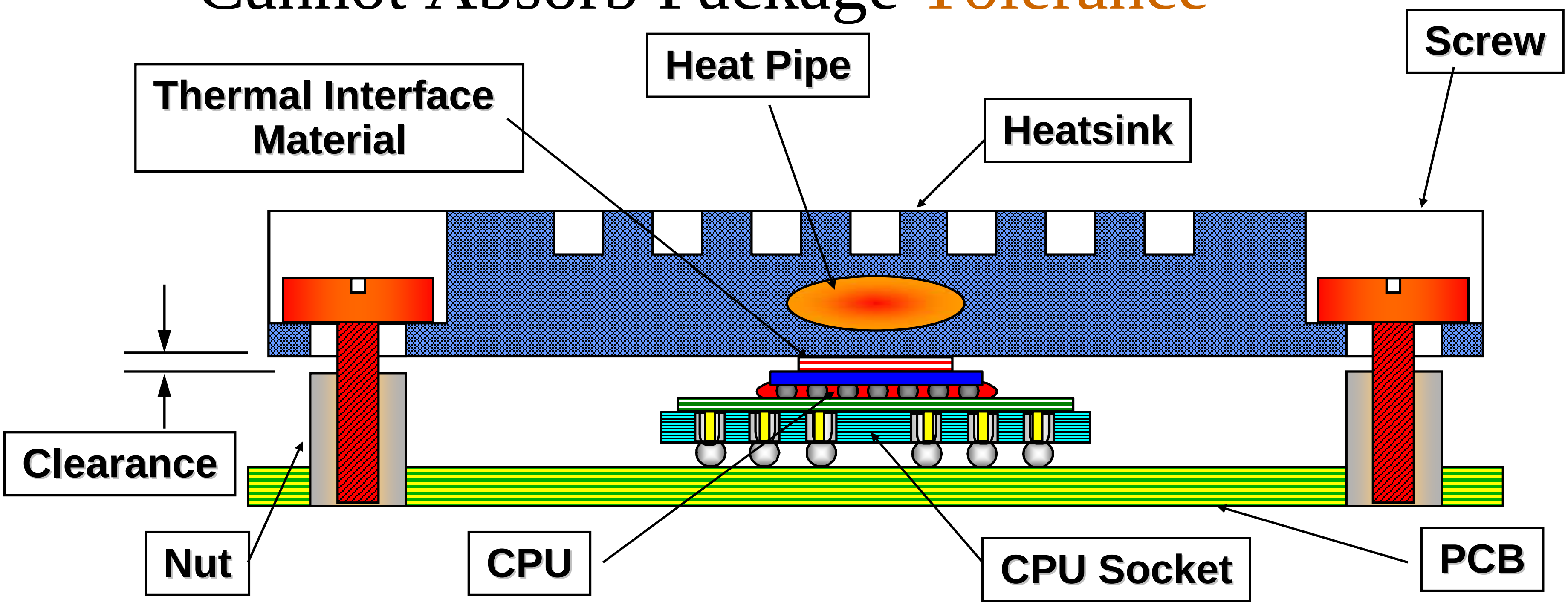
100 lbf static



Mobile CPU is Fragile

Old Design : Board Referencing

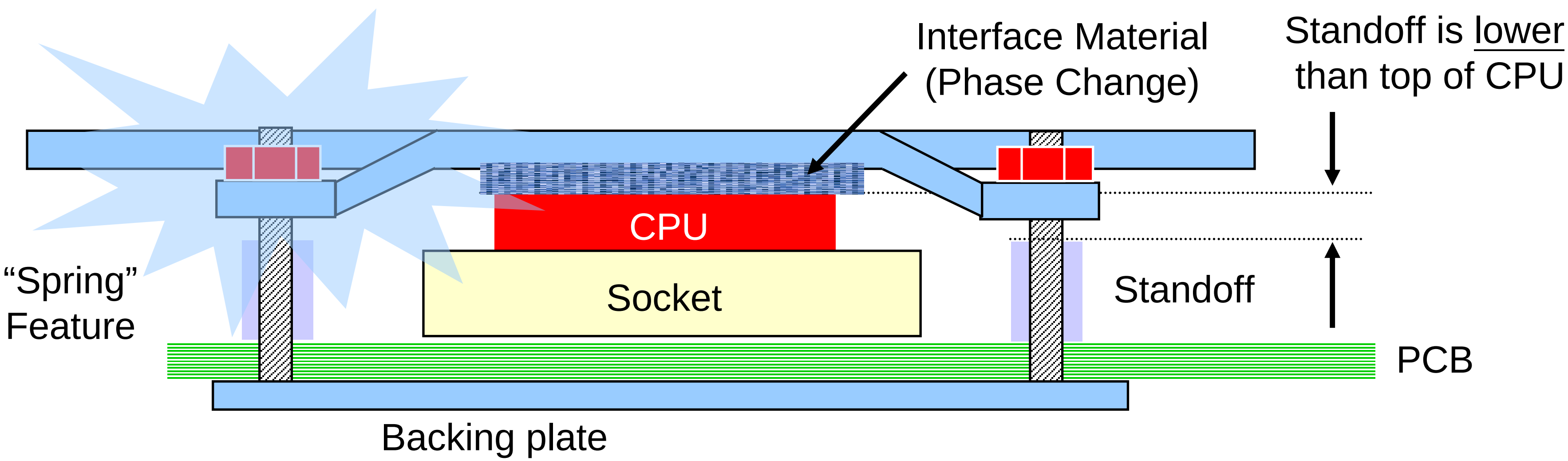
- No Pressure Control
- Cannot Absorb Package Tolerance



Old Design Cannot Control Contact Pressure

Thermal Attach: Die-Referencing

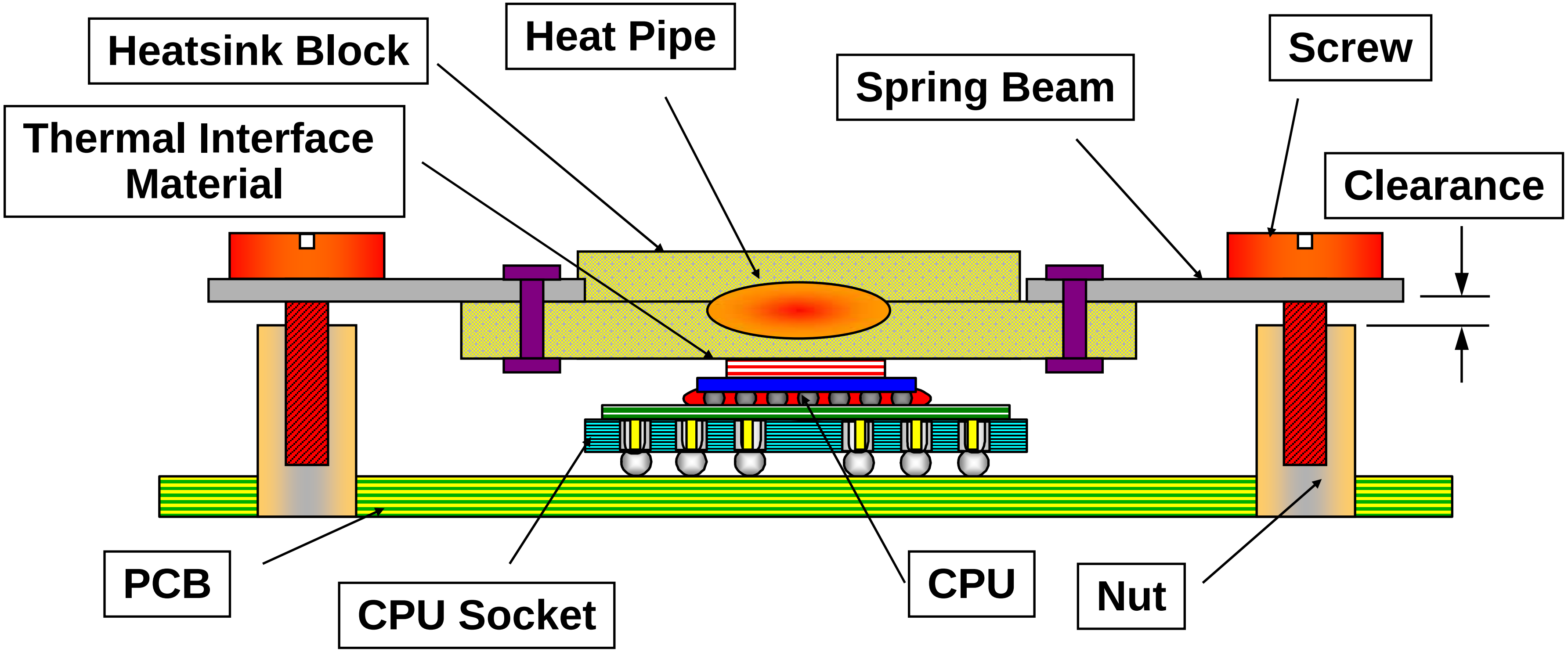
- Die Reference Advantage: "spring feature"
  - Automatic adjustment to CPU height tolerances
  - Create uniform and constant die pressure



Use Die-Referencing for NB CPU Die Attach

Thermal Attach: Die-Referencing

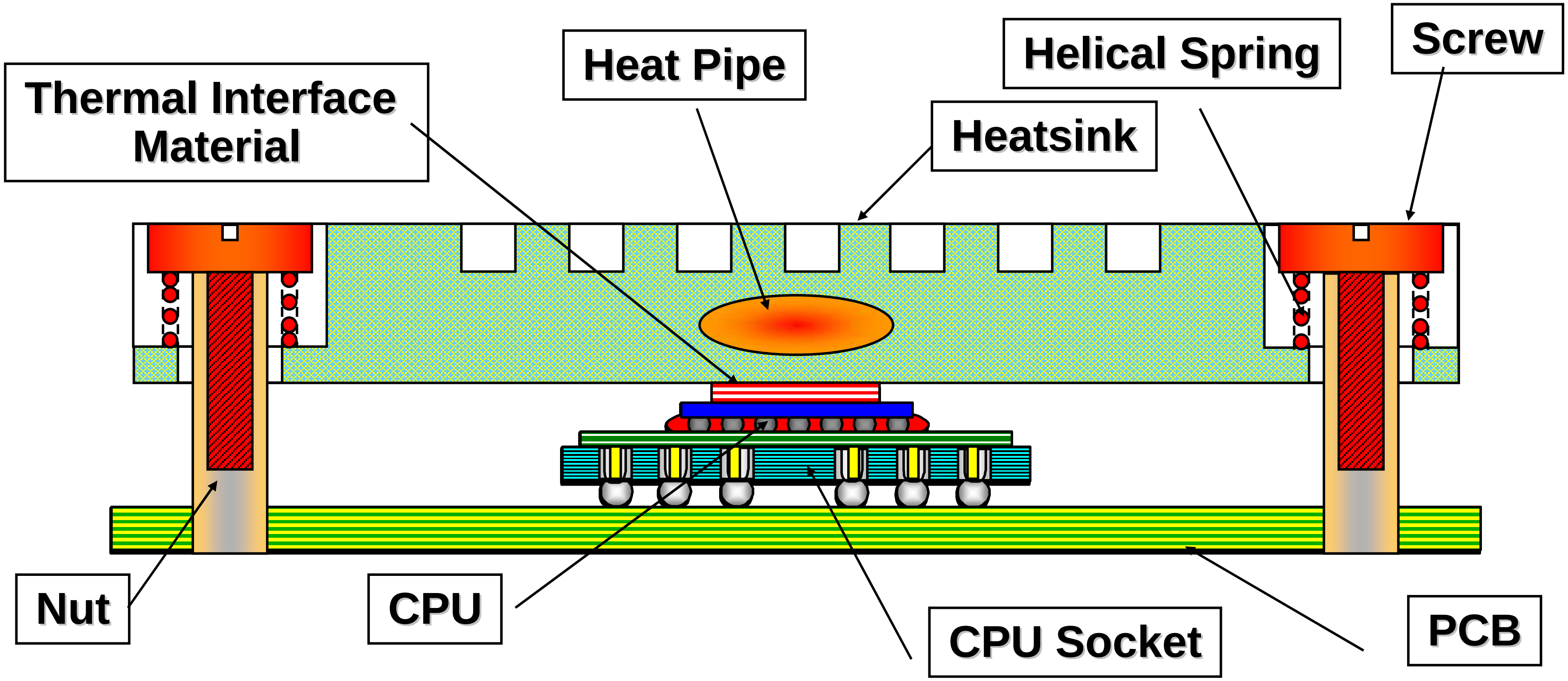
- Typical Spring Beam Design



Spring Beam Saves Space, But not Easy to Design

Thermal Attach: Die-Referencing

- Typical Helical Spring Design



Helical Spring is Easy to Design, But Wastes Space

Home work

1. Estimate the heat dissipated by passive heat transfer

Home work

2. Estimate the heat dissipated by a 60 mm(W) x 20 mm(L) x 17 mm(H) heat exchanger.