Closer Tolerance Thermal Management at the Device-Under-Test

Bert Brost
Senior Product Manager
bert.brost@cohu.com

Abstract:

Effective thermal management has become mandatory for testing devices with faster switching speed transistors that are increasing in numbers in smaller packages. These devices are dissipating more heat while being held at steady test temperature extremes. In most cases, the heat will exit the device-under-test by conduction through the probes in the contactor. Newer probe technologies incorporate in-probe radiation features to support convection for thermal management along with two-point contact for effective conduction heat removal.

Since these are based on convection and conduction heat removal, it is important that one understands and apply Rɵ (thermal resistance) as it relates to the probes impact on thermal management. We must consider this with Rɵ being equal to L/(κ * A) where L= length, κ=thermal conductivity of probe material, and A=cross-sectional surface area. Rɵ = L/(κ * A) is only one part of a systemic understanding of what is required from today's high performance contactors. This paper will describe how newer probe technologies are being deployed to improve thermal management at the device-under-test while reducing the need for large test handler thermal offsets.

12367 Crosthwaite Circle
Poway, CA 92064-6817
Phone: (858) 848-8100
Fax: (858) 848-8185
www.cohu.com

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Bert Brost and Mehdi Ataran
Cohu

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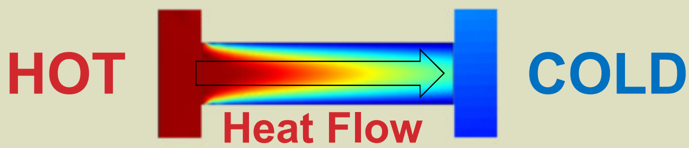
Thermal Management

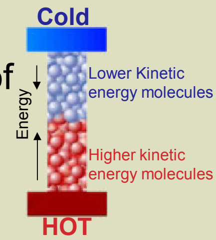
- Thermal Management is the ability to control the temperature of a system
- Heat by definition is energy in transit due to a temperature difference Heat flows from higher temperature to lower temperature

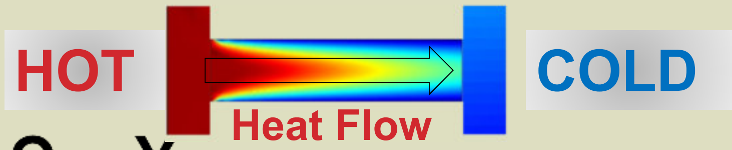


Nature Likes Balance

Temperature and Heat

- What is temperature and what is heat
  - Temperature is the physical property which determines the direction of heat flow
  - Temperature is the physical property of a system that provides a measure of hotness or coldness
  - Temperature is a measure of the average kinetic energy of molecules in a body
  - Heat flows from higher temperature to lower temperature





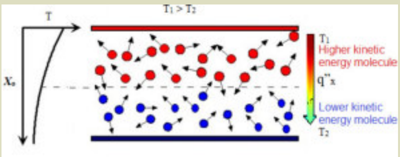
Analogies

- Electrical engineers use Ohm's law as an analogy when doing thermal resistance calculations
- Mechanical and structural engineers use Hooke's Law and use it as an analogy when doing thermal resistance calculations

Type	Structural Analog	Hydraulic Analogy	Thermal	Electrical
Quantity	… . . . […]	Volume V [m³]	Heat Q [J]	Charge q[C]
Potential	Displacement X[m]	Pressure P[n/m²]	Temperature T[K=j/k_b]	Potential V[V=J/C]
Flux	Load of force F [N]	Flow rate Q [N/m³/s]	Heat Transfer rate Q [W=J/s]	Current I [A=C/s]
Flux Density	Stress σ[Pa=N/m²]	Velocity **v**[m/s]	Heat Flux q [W/m²]	Current Density **j** [C/(m²· s)=A/m²]
Resistance	Flexibility 1/k […]	Fluid resistance R[…]	Thermal Resistance R [K/W]	Electrical Resistance R [Ω]
Conductivity	Stiffness k [N/m]		Thermal Conductivity 1/R [W/(K·m)]	Electrical Conductance 1/R […]
Lumped element linear model	Hooke's Law ΔX=F/k	Hagen-Poiseuille Equation P=QR	Newton Law of Cooling T=QR	Ohms Law V=IR
Distributed linear model	… . . .		Fourier's law Q=-k∇T	Ohm's law J=σE

Heat Transfer

- Heat flows in response to a temperature gradient
- If two points are in thermal contact and at different temperatures, (e.g., T 1 and T 2) then energy is transferred between the two in the form of heat, Q
- The rate of heat flow from T1 to T2 depends on the two temperatures and the material conductivity
- If heat flows from hot to cold, (the standard convention)



$$Q = \frac{kA}{l}(T_1 - T_2)$$

A is area
l is length
k is thermal conductivity

Thermal diffusivity of selected materials and substances	
Material	Thermal diffusivity (mm²/s)
Gold	127
Copper at 25 °C	111
PVC (Polyvinyl Chloride)	0.08
Brick, adobe	0.27
Wood (Yellow Pine)	0.082

In heat transfer analysis: Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure

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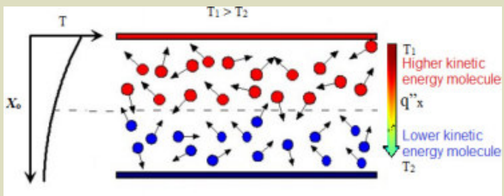
Conduction Heat Transfer

$$q''_x = -k\frac{dT}{dx} \qquad \frac{dT}{dx} = \frac{T_2 - T_1}{L}$$

- *q*" is the heat flux i.e., the heat transfer rate
- *x* is the transfer rate per unit area perpendicular to the direction
- *k* is the thermal conductivity (W/m) and is characteristic of the contact probe material and device lead material
- \- the minus sign is a consequence of heat transferred in the direction of decreasing temperature
- In short: Heat flow is in response to temperature gradient

If two points are in thermal contact and at different temperatures, T1 and T2, then energy is transferred between the two



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Forced Convection Heat Transfer

Convection is heat energy transferred between a surface and a moving fluid with different temperatures as convection.

A fluid is anything that has loosely moving molecules that can move easily from one place to another, i.e., Liquids and gases

Though the convection thermal transport is more complicated than with conduction, convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate). Fluid motion and convection go beyond the scope of the paper.

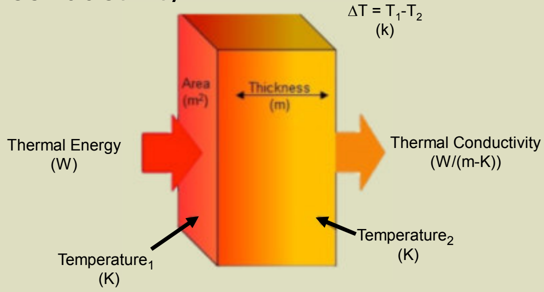
The basic convection heat transfer equation is quite simple: $q = k A \Delta T$ (Fourier's Law)

- *q*" is the heat flux i.e., the heat transfer rate (*Q is heat transport per unit of time)*
- *k* is the thermal conductivity (W/m) and is characteristic of the contact probe material and device lead material
- A is the heat transfer area of the surface (m^2)
- ΔT is the difference between the surface and the bulk fluid (°C)

Good Thermal Management /Heat Transfer at the Device-Under-Test

- Conduction and Forced Convection heat transfer
  - Required:
    - A low pin surface Ra value with repeatable pin force biasing
    - A large surface area
    - A *material with good* thermal conductivity

Poor surface-to-surface heat conduction



cDragon

Lower Kinetic energy molecules

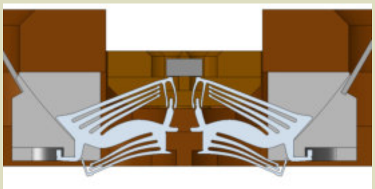
Higher kinetic energy molecules

- Thermal
  - Multi beam design allows for better airflow thru contact pin elements
    - Integrated airflow tunnels allow the pins to remain very close to handler’s set temperature during testing
    - Heat by definition is energy in transit due to a temperature difference

Conduction

$$Q = \frac{kA}{l}(T_1 - T_2)$$

- *Q is heat transport per unit of time*
- A is area
- l is length
- k is thermal conductivity



Nature Likes Balance

T1 = T2

Convection

$$q = k\,A\,\Delta T$$

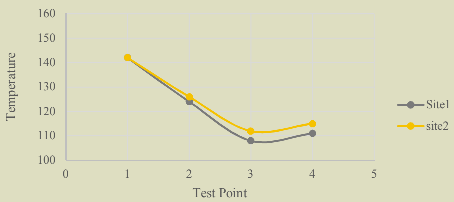
- q” is the heat transfer rate k is the thermal conductivity
- A is the heat transfer area of the surface (m^2)
- ΔT is the difference between the surface and the bulk fluid (°C) temperature

Customer Validation

- Imbedded Thermal Diode (LT8614)

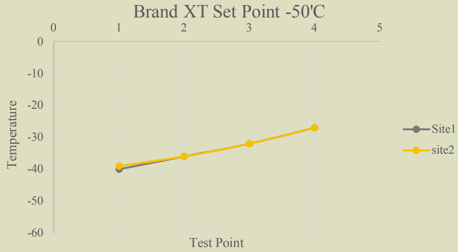
Lot	#893476	QTY=750
Roll200XT	Site1	site2
T1	142	142
T2	124	126
T3	108	112
T4	111	115

Brand XT set Point 158'C



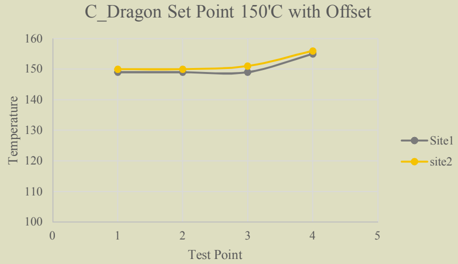
Lot	#893476	QTY=1000
Roll200XT	Site1	site2
T1	-40	-39
T2	-36	-36
T3	-32	-32
T4	-27	-27

Brand XT Set Point -50'C

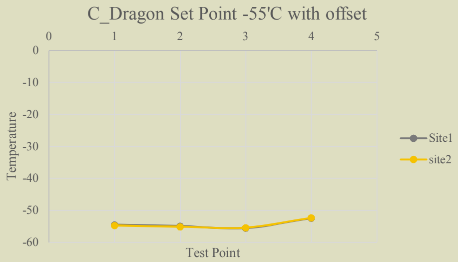


Customer Validation

Lot	#	QTY=200
C_Dragon	Site1	site2
T1	149	150
T2	149	150
T3	149	151
T4	155	156



Lot	#	QTY=200
C_Dragon	Site1	site2
T1	54.5	-54.7
T2	-54.9	-55.1
T3	-55.5	-55.4
T4	-52.4	-52.3



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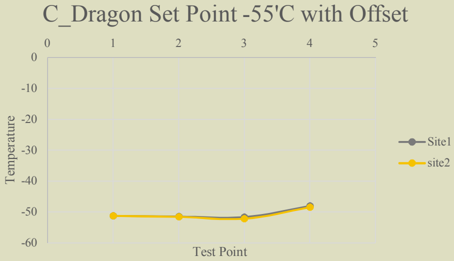
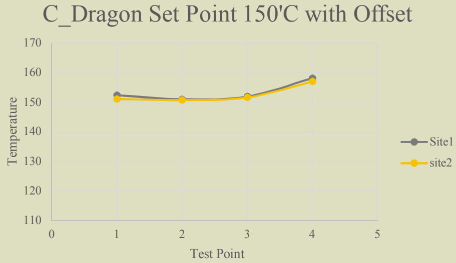
Customer Boxstock Testing

Lot	#	QTY=3000
C_Dragon	Site1	site2
T1	-51.3	-51.3
T2	-51.5	-51.6
T3	-51.7	-52.2
T4	-48.1	-48.5



Lot	#	QTY=4200
C_Dragon	Site1	site2
T1	152.4	151.1
T2	151	150.7
T3	151.9	151.6
T4	158.1	157



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Thank You

From
Bert, Mehdi, and everyone at Cohu

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References

- The Exact Analytical Conduction Toolbox contains a variety of transient expressions for heat conduction, along with algorithms and computer code for obtaining precise numerical values.
- *Sam Zhang; Dongliang Zhao (19 November 2012). Aeronautical and Aerospace Materials Handbook. CRC Press. pp. 304–. ISBN 978-1-4398-7329-8. Retrieved 7 May 2013.*
- *Martin Eein (2002). Drop-Surface Interactions. Springer. pp. 174–. ISBN 978-3-211-83692-7. Retrieved 7 May 2013.*
- Bailyn, M. (1994). *A Survey of Thermodynamics*, American Institute of Physics, New York, ISBN 0-88318-797-3, page 23.
- Thermal Conductivity analyzer http://www.aicplindia.com/pdf/zaf.pdf
- Psota, B.: The Increasing Importance of the Thermal Management for Modern Electronic Packages, Electronic Devices and Systems Conference Proceedings, Brno, 2012
- Thermal Considerations for QFN Packaged Integrated Circuits. In: Analog and Digital Processing ICs, Semiconductor Company, Cirrus Logic: [online]. [cit. 2012-04-28]. Web: http://www.cirrus.com/en/pubs/appNote/AN315 REV1.pdf
- FREESCALE SEMICONDUCTOR, Inc. Thermal Analysis of Semiconductor Systems [online]. 2008 [cit. 2012-04-04]. Web: http://www.freescale.com/files/analog/doc/white _paper/BasicThermalWP.pdf
- Jamia A.: Practical Guide to the Packaging of Electronics-Thermal and Mechanical Design and Analysis. New York: Marcel Dekker, Inc., 2003. ISBN 0-8247-0865-2.
- CIRRUS LOGIC. Thermal Considerations for QFN Packaged Integrated Circuits [online]. 2008 [cit. 2012-04-04]. Web: http://www. cirrus.com/en/pubs/appNote/AN315REV1.pdf

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