Power Transistor Heat Sink Design Trade-offs

Presenter:
Prof. Tom Eppes

Co-authors:
Prof. Ivana Milanovic & George Quarshie
**University of Hartford, USA**

Project Motivation

- **Selection decision can result in over-design**

- **Heat transfer process sometimes over-simplified**

- **Trade-offs of size, material & air flow not well understood**

- **Modeling straightforward, not computationally expensive**

TO-220 Package and Heat Sink Attachment

- **Internal transistor die**
- **Mounted to plastic chip carrier (PLCC)**
- **Three wire-bonded gold leads**
- **Three external copper leads to PCB**
- **Stainless steel tab (AISI 4340)**
- **Thin mica insulator**
- **Aluminum 6063 heat sink**
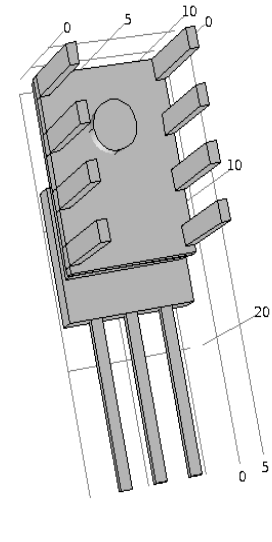
Constraints and Boundary Conditions

- **Transistor die - internal boundary layer heat source**
- **Conduction, convection, and radiation**
- **Neglect joule heating in conductors**
- **Ambient air temperature +20°C**
- **Printed circuit board fixed to +30°C**
- **Seven material interfaces**
- **Steady-state and time-dependent solutions**

Surface: Temperature (K)
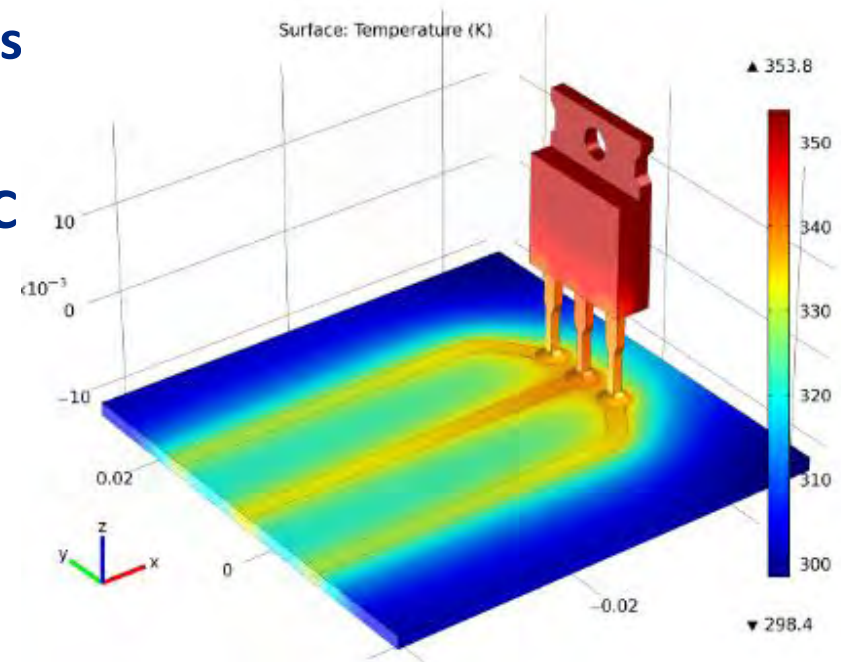
Heat Transfer Physics in Solids

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \circ \left(k \nabla T \right) = Q$$

where

ρ = density (kg/m³)

C_p = heat capacity (J/kgK)

k = thermal conductivity (W/mK)

Q = heat source (W/m²)

T = temperature (K)

t = time (s)

Convective Cooling Condition

$$-n \cdot \left(-k\nabla T \right) = h\left(T_{amb} - T \right)$$

where   **n = unit vector normal to the surface**

                        h = heat transfer coefficient (W/m²K)

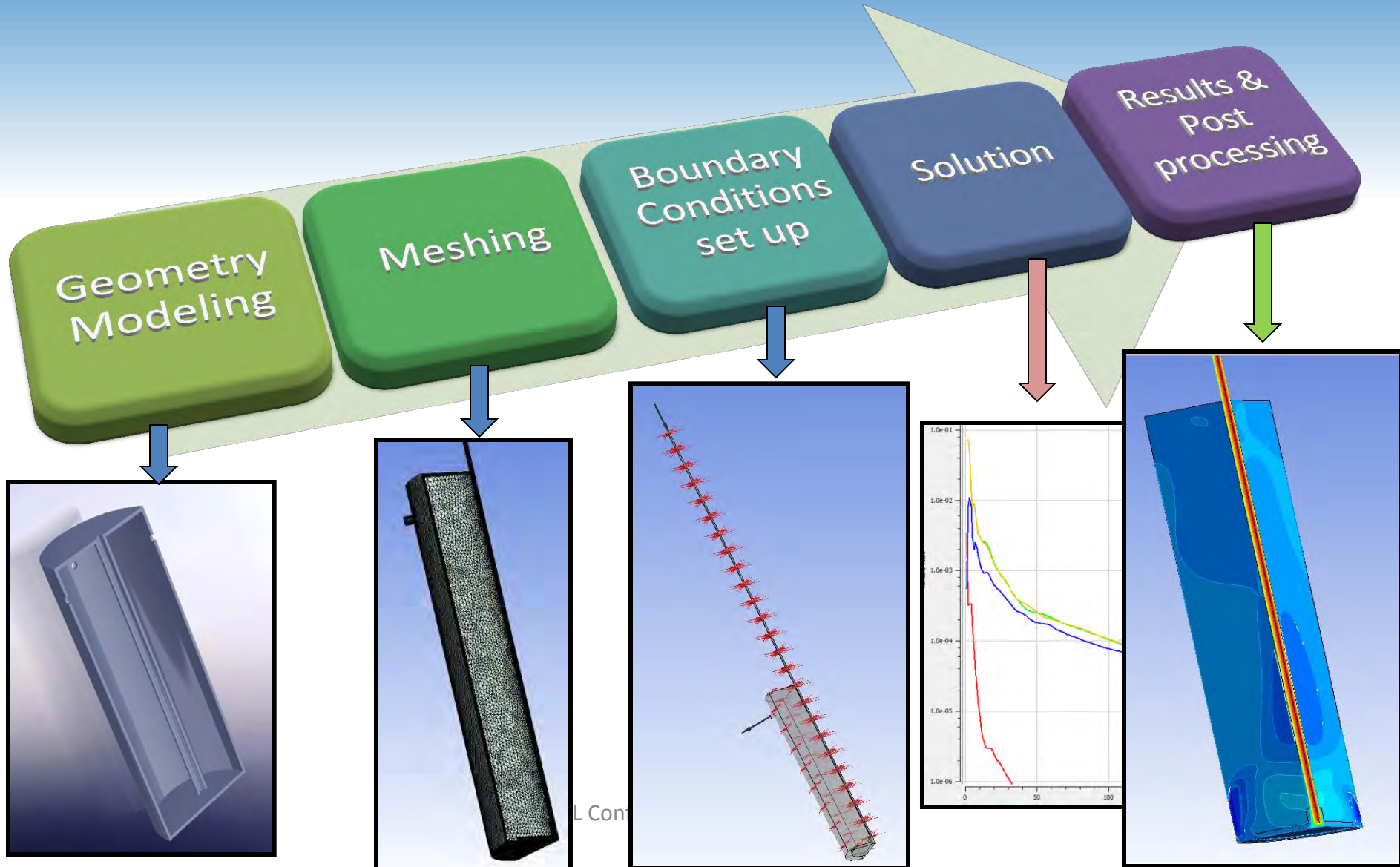   **T_{amb} = ambient temperature (K)**

Ambient Radiation Condition

$$-n \cdot \left(-k\nabla T\right) = \varepsilon\sigma\left(T_{amb}^4 - T^4\right)$$

where   **ε = emissivity**

σ = Stefan-Boltzmann constant = 1.38e-23 (J/K)

# Multiphysics Modeling Procedure

Materials and Properties

Material	Density (kg/m^3)	Heat Capacity (J/kgK)	Thermal Conductivity (W/mK)
Silicon	2,300	710	150
Copper	8,700	385	400
Gold	19,300	129	318
PLCC	900	1,700	0.2
Steel AISI 4340	7,850	477	54
Mica	2,883	500	0.71
Aluminum Alloy 6063	2,700	900	200

Radiation to Ambient

| Material	Emissivity
Copper	
PLCC	0.85
Stainless steel (AISI 4340)	
Black anodized aluminum alloy 6063	0.77

Meshed Geometry

- **General physics pre-defined (normal)**
- **Maximum size – 2.9 mm**
- **Minimum size – 0.52 mm**
- **66,335 elements**
- **93,040 degrees of freedom**
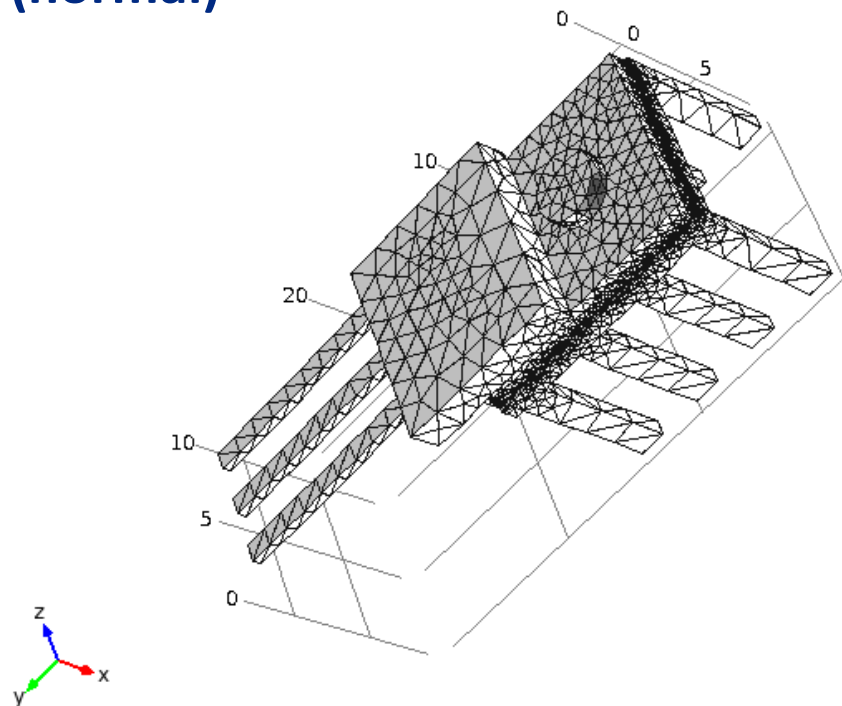
Solvers Used

- **MUMPS – Parallel sparse direct solver**
- **GMRES – Generalized minimal residue iterative solver**
- **Paradiso – Parallel sparse direct solver**
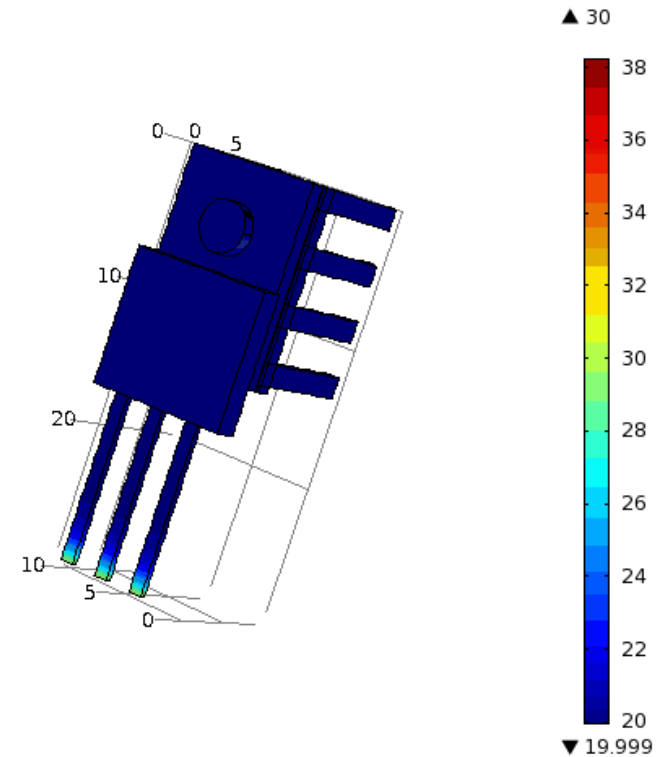- **BDF(k) – Time dependent solver**
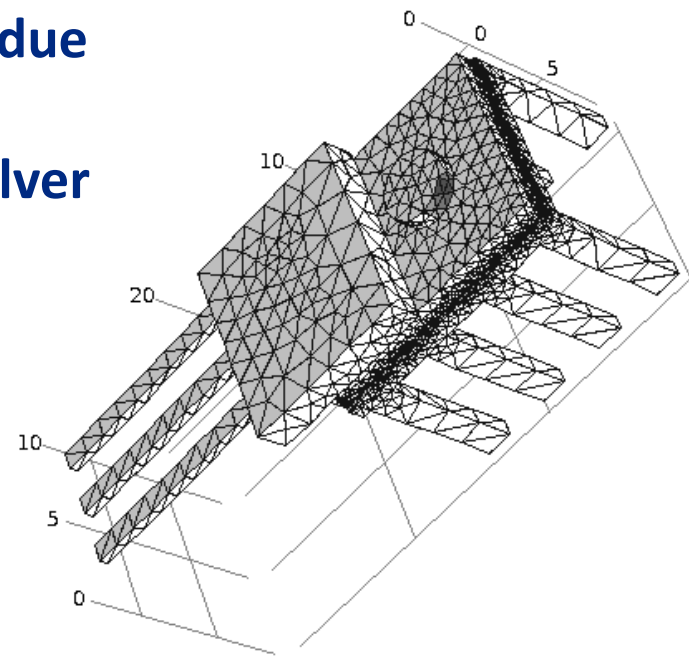
Surface Temperature Distribution (Base Case)

- **0.5W input power**
- **+20°C ambient air temperature**
- **Minimal convection (5W/cm²K) with radiation**
- **Maximum temperature +47.3°C**
- **Minimum temperature + 30°C**
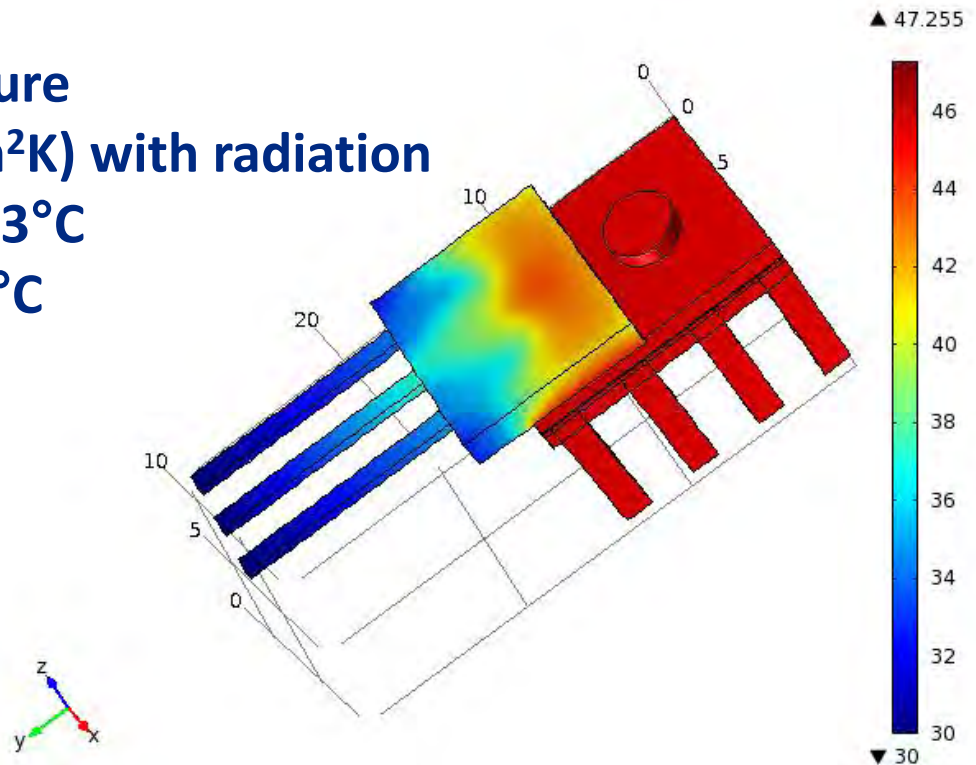
Surface Temperature on Power Up

- **Base case settings**
- **0 - 60 seconds timeframe**
- **Immediate heat flow into leads**
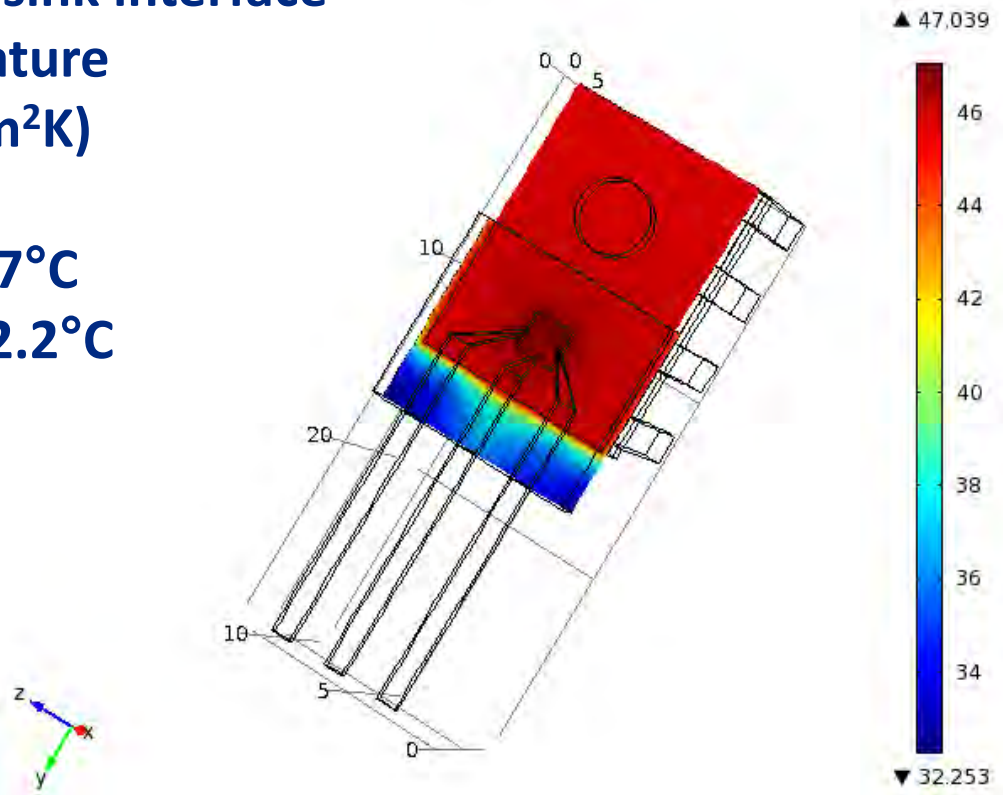- **Eventually into heat sink**

Effects of Transistor Power

Transistor Power (Watt)	Temperature Resistance (°C/Watt)
0.5 (Base case)	54.2
1.0	46.9
1.5	44.0
2.0	42.3
2.5	41.1
3.0	40.2

Temperature Slice (Base Case)

- **Stainless steel tab to heat sink interface**
- **+20°C ambient air temperature**
- **Minimal convection (5W/m^{2}K)**
- **With radiation**
- **Maximum temperature +47°C**
- **Minimum temperature +32.2°C**

Temperature Distribution (Base Case)

Geometric Location	Temperature (°C)	Temperature Resistance (°C/Watt)
Transistor die	**+47.1**	**+54.2**
Case front	**+47.0**	**+54.0**
Case back-mica	**+46.4**	**+52.8**
Mica-heat sink front	**+45.7**	**+51.4**
Heat sink back	**+45.6**	**+51.2**
Heat sink mid-fin	**+45.4**	**+50.8**

Impact of Heat Sink Area

Heat Sink Area (relative)	Die Temperature (°C)	Temperature Resistance (°C/Watt)
Base case - 0%	+47.1	+54.2
+10%	+46.6	+53.2
+20%	+46.0	+52.0
+30%	+45.5	+51.0
+40%	+45.1	+50.2
+50%	+44.6	+49.2

Impact of Convective Cooling

Convection Coefficient (W/m^2-K)	Die Temperature (°C)	Temperature Resistance (°C/Watt)
5 (Base case)	+47.1	+54.2
15	+41.5	+43.0
25	+38.0	+36.0
35	+35.6	+31.2
45	+33.9	+27.8
55	+32.7	+25.4

Radiation to Ambient Effects

Emissivity	Die Temperature (°C)	Temperature Resistance (°C/Watt)
Base case (on)	+47.1	+54.2
Off	+51.7	+63.4

Thanks!

Questions?   Comments?   Feedback?