BiTS™

# Burn-in & Test Socket Workshop

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## ARCHIVE

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Burn-in & Test
Socket Workshop

# Technical Program

## Supplemental Paper
## Monday 3/07/05 3:30PM

# "Characterization Of Maximum Current Capability For Microprocessor Sockets"

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*2005 Burn-In & Test Sockets Workshop*

# Characterization of Maximum Current Capability for Microprocessor Sockets

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Design Process Development / ATD
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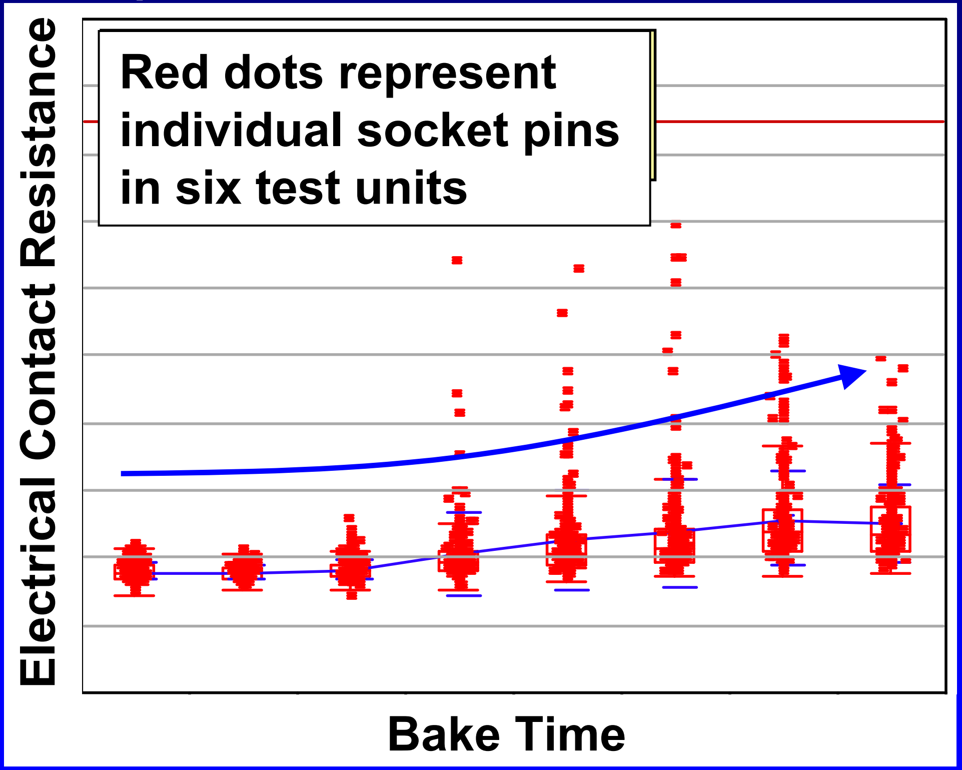
| Todd Young | Seth Reynolds |
| Edward Lawton | Tom Paddock |

# Agenda

- Motivation for Thermal Analysis of Socket ▶|
- Socket Maximum Current Capacity ▶|
- Numerical Model for contact temperature prediction ▶|
- Experimental Model Validation
  - Infrared Imaging DOE ▶|
- ΔT Prediction by Empirical Model ▶|
- Key Summary ▶|
- Glossary ▶|

# Motivation for Thermal Analysis of Socket

- Electrical contact resistance of a socket impacts the electrical performance of the whole product.
- Reliability bake data shows that contact temperature impacts the electrical contact resistance significantly.



Red dots represent individual socket pins in six test units

Possible root causes:

–Mold softening

–Contact surface oxidation (Ni/Cu)

–Mechanical relaxation of cantilever

→Temperature-accelerated failure mechanism.

**Thermal Runaway at the Contact**


**↑ Resistance → ↑ Joule Heating → ↑ Temperature**

# Socket Current Carrying Capacity (IMAX)

- **Current carrying capacity is determined by:**

  ***Maximum allowed contact temperature***, above which contact resistance accelerates and thermal runaway occurs.

  ***Risk level assessment*** against this temperature limit, based on actual product boundary conditions.

- Current BKM uses a **local model**: a single socket pin

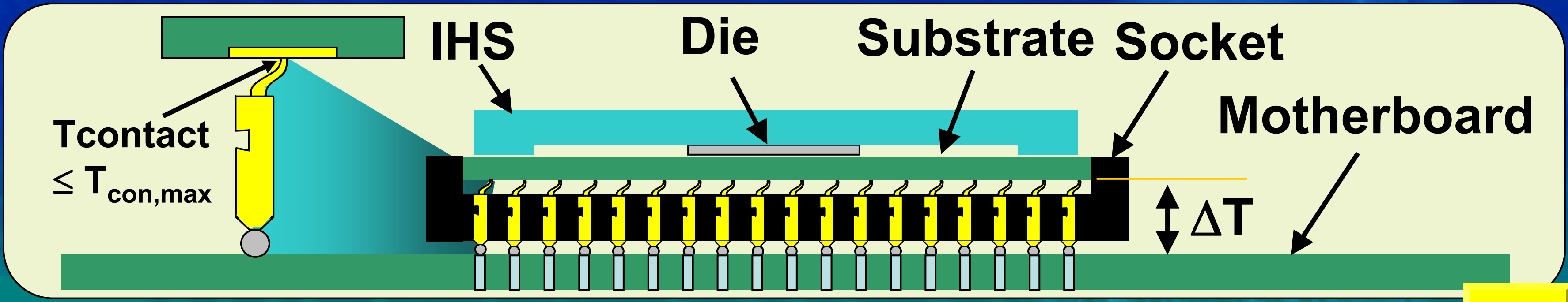
  Find the ***temperature drop across a socket pin:*** ΔT

  →Limit motherboard temperature: $T_{board,max} = T_{Con,max} – \Delta T$

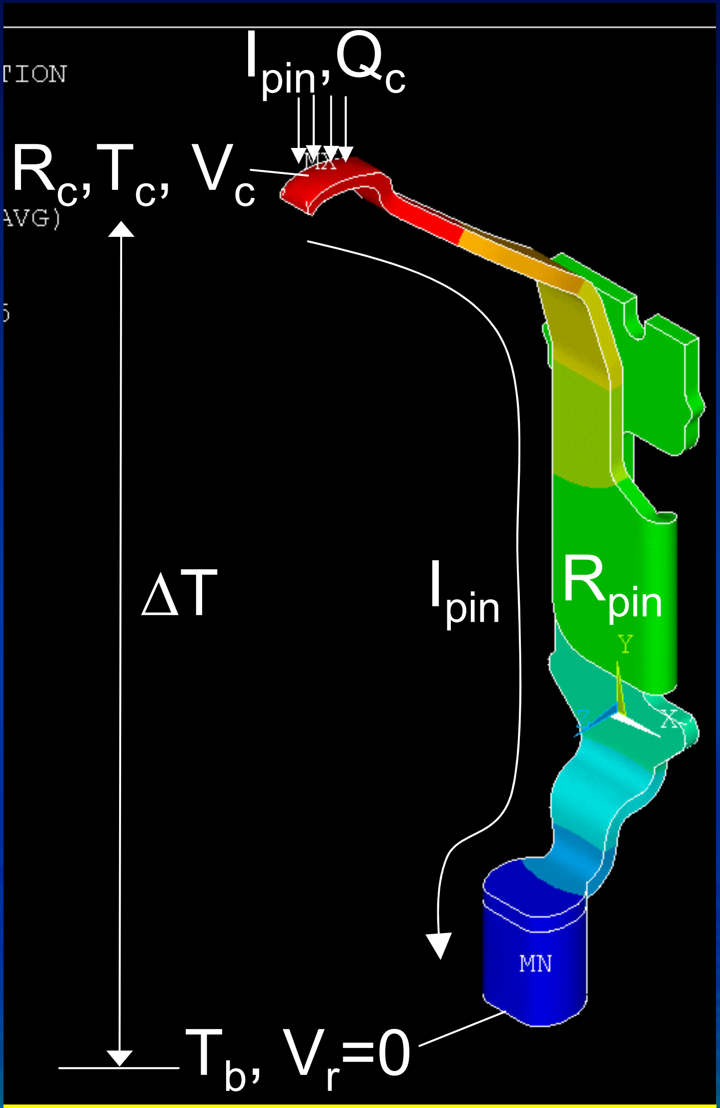
- Existing model is purely computational:

  –FEM by coupling thermal and electrical elements.

- OBJECTIVE: Experimentally validate the numerical model.



# Numerical Model for Contact Temperature Prediction



**Sample ANSYS Model**

-Adiabatic boundaries except the base of the solder ball

***Caveats:***

→ ***Substrate effect is ignored***

→ All heat flows ***downward.***

-Thermoelectrical modeling:

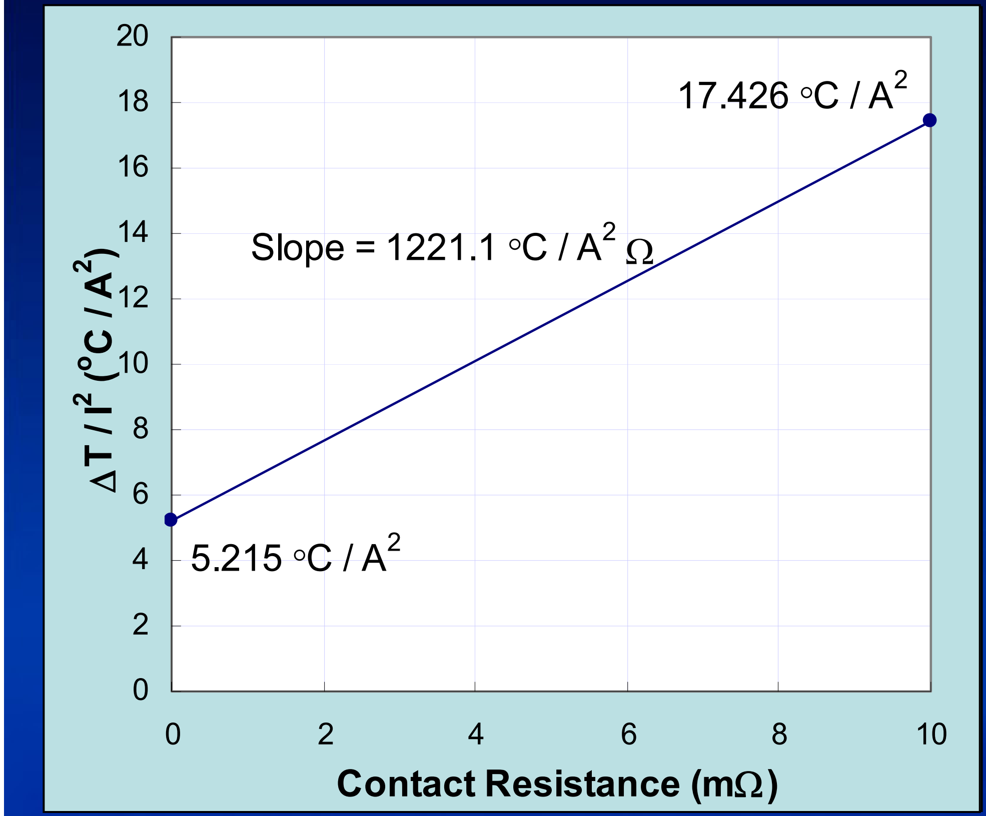
Uses $\rho$ and k.

-Zero voltage and constant temperature at the base.

-Apply electrical current at the top (contact point).

-Electrical contact resistance is represented by ***extra Joule heating*** at the contact.

# ANSYS Model: Modeling Results



$$\Delta T = \underbrace{a\, I_c^2}_{\text{Bulk}} + \underbrace{b\, I_c^2 R_c}_{\text{Contact}}$$

Fitting constants: a & b

Resistivity: ρ ↑

Thermal conductivity: k ↓

Length of contact pin: L ↑

Cross-sectional area: A ↓

**How to determine a:**

$a = 5.215\ ^\circ C/A^2$

**How to determine b:**

$b = 1221.1\ ^\circ C/A^2\ \Omega$

$$\Delta T = 5.215\, I^2 + 1221.1\, I_c^2 R_c$$

### Key Results

$$\Delta T \propto I_c^2$$

**$\Delta T \propto$ Contact Resistance**

# Example of Motherboard Temperature Spec

**Per-Pin Current (assumed),**

$I_c$ = 1A / pin

**Pin resistance (Pin + Contact),**

$R_{pin}$ = 20 mΩ

**Contact Resistance Portion**

$R_c$ = 10 mΩ

**Temperature Drop Across Socket Pin:**

$$\boxed{\Delta T = 5.215\, I_c^2 + 1221.1\, I_c^2 R_c}$$

$\Delta T$ (Imax = 1 A, Rc = 10 mΩ) = 17.43 ˚C

**$T_{con,max}$ is assumed to be <u>100 °C</u>.**

**Board Temperature Spec:**

**maximum board temperature is,**

$T_{max,board} = T_{con,max} - \Delta T$ = 100 ˚C – 17.43 ˚C = ***<u>82.57 ˚C</u>***

# Experimental Model Validation of Socket IMAX

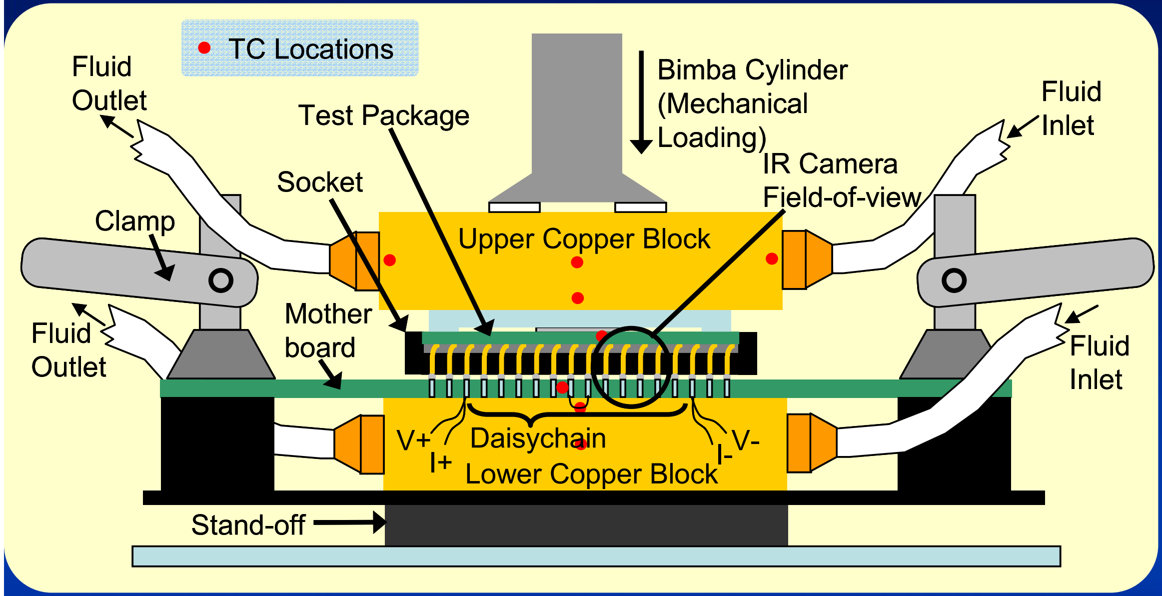
- Measure temperature of an entire socket pin from contact to the base.
  - Need the temperature profile of socket pin as a function of substrate temperature, motherboard temperature, contact resistance, and pin current.
  - Contact resistance is controlled by varying mechanical load on socket.
- A non-contact temperature measurement desired:
  - Thermocouple (TC) will draw heat away, cooling the pin.
  - TC junction is too large to fit into the contact point.

  → Perform infrared imaging thermometry on a socket cross-section.

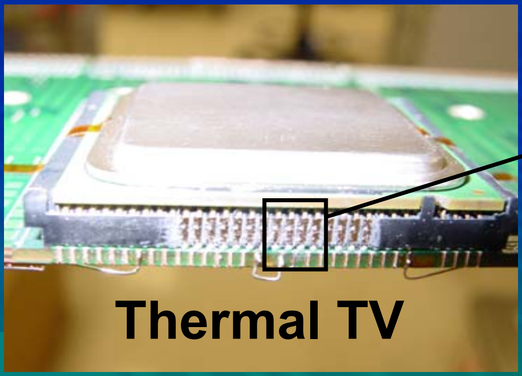
To Glossary ▶|

# Experimental Setup

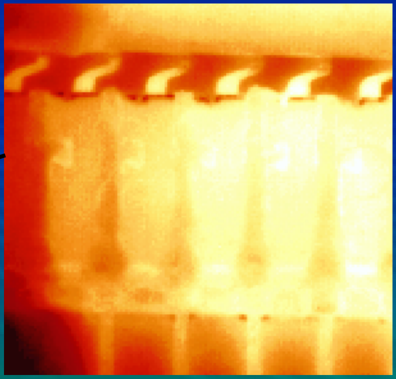
- Schematics

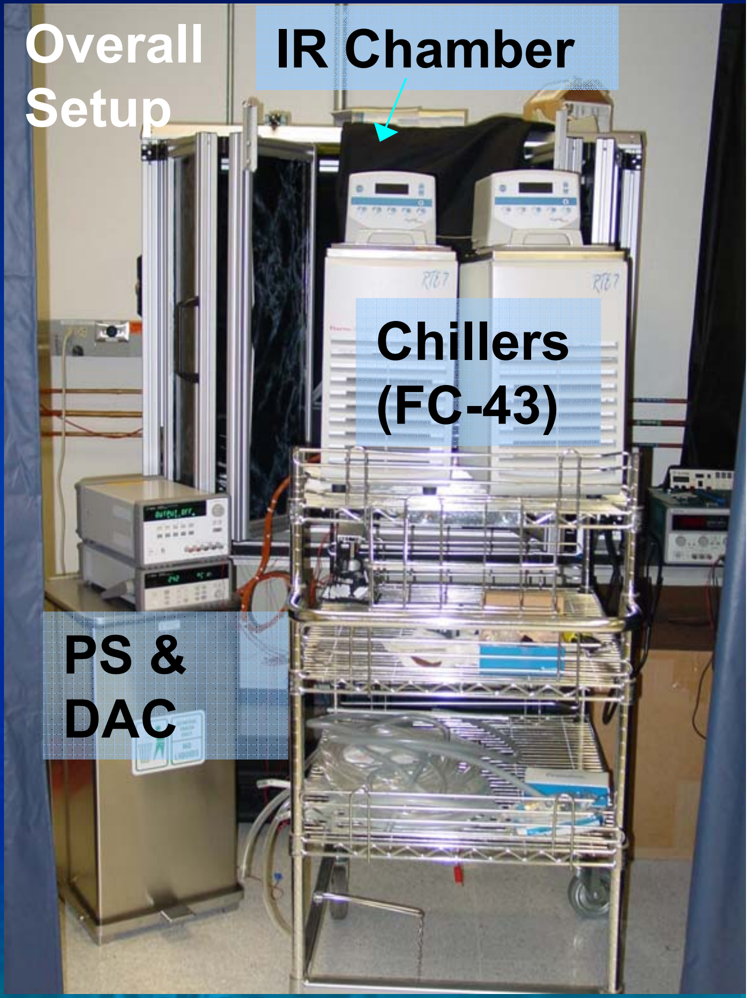


Cross-cut Socket



IR Image





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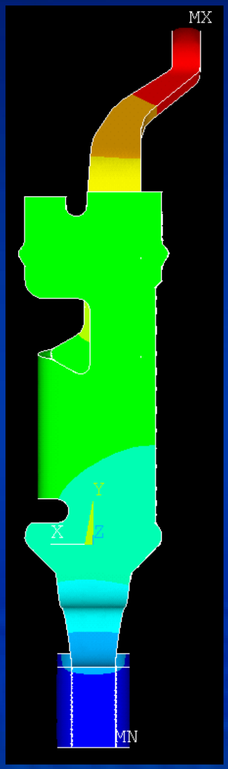
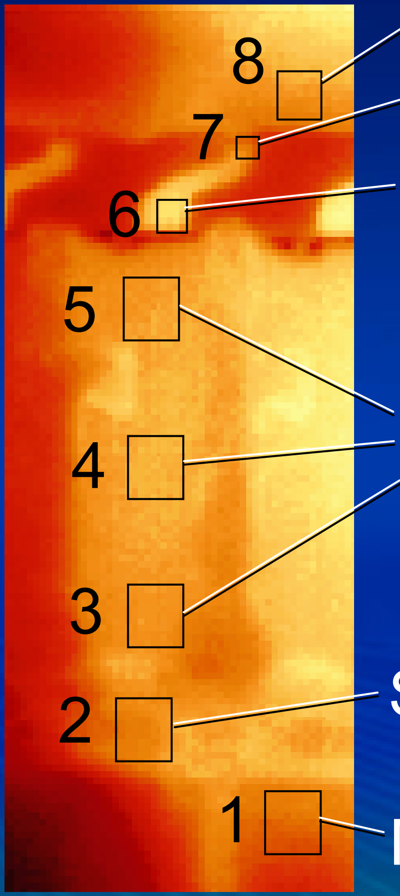
# Socket Pin Temperature Profile

- 8 locations along the pin → 1-D Temperature profile





Substrate

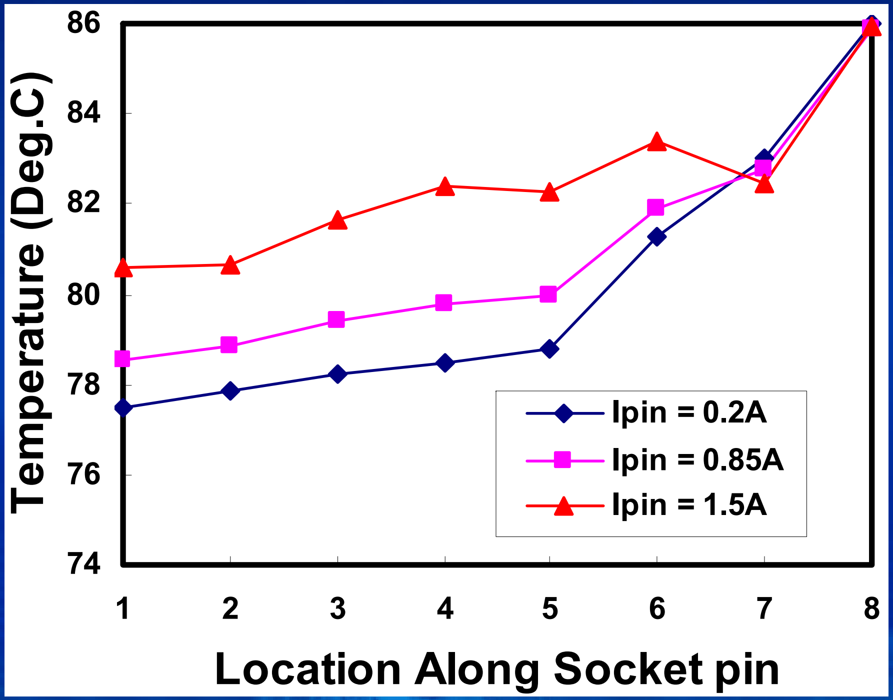
Contact

Pivot of Cantilever

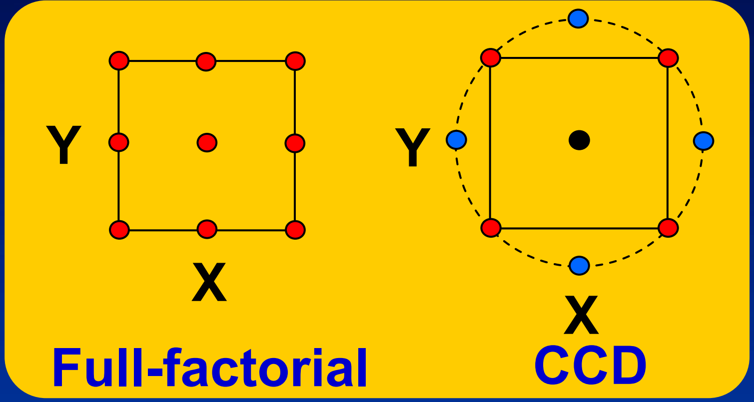
Pin body

Solder Ball

Motherboard



# DOE: Central Composit Design



- Reduce the number of data points to be collected
- For a 4-parameter, 3-point DOE, a full-factorial design requires 81 data points.
- Central composite design offers a 4-parameter, 5-point DOE in 26 data points.

🟥 Maximum 🟦 Minimum

| Number | Pattern | Tsub (°C) | Tboard (°C) | Current (A) | Air Pressure (psi) |
|---|---|---|---|---|---|
| 1 | 0000 | 85.00 | 75.0 | 0.850 | 40.0 |
| 2 | 00a0 | 85.00 | 75.0 | 0.200 | 40.0 |
| 3 | 00A0 | 85.00 | 75.0 | 1.500 | 40.0 |
| 4 | 0a00 | 70.00 | 60.0 | 0.850 | 40.0 |
| 5 | 0A00 | 100.00 | 90.0 | 0.850 | 40.0 |
| 6 | a000 | 75.00 | 75.0 | 0.850 | 40.0 |
| 7 | A000 | 95.00 | 75.0 | 0.850 | 40.0 |
| 8 | 0000 | 85.00 | 75.0 | 0.850 | 40.0 |
| 9 | 000a | 85.00 | 75.0 | 0.850 | 20.0 |
| 10 | 000A | 85.00 | 75.0 | 0.850 | 60.0 |
| 11 | --++ | 68.18 | 64.9 | 1.288 | 53.5 |
| 12 | ---+ | 68.18 | 64.9 | 0.412 | 53.5 |
| 13 | +--+ | 81.58 | 64.9 | 0.412 | 53.5 |
| 14 | +-++ | 81.58 | 64.9 | 1.288 | 53.5 |
| 15 | -+++ | 88.42 | 85.1 | 1.288 | 53.5 |
| 16 | -+-+ | 88.42 | 85.1 | 0.412 | 53.5 |
| 17 | ++-+ | 101.82 | 85.1 | 0.412 | 53.5 |
| 18 | ++++ | 101.82 | 85.1 | 1.288 | 53.5 |
| 19 | --+- | 68.18 | 64.9 | 1.288 | 26.5 |
| 20 | ---- | 68.18 | 64.9 | 0.412 | 26.5 |
| 21 | +--- | 81.58 | 64.9 | 0.412 | 26.5 |
| 22 | +-+- | 81.58 | 64.9 | 1.288 | 26.5 |
| 23 | -++- | 88.42 | 85.1 | 1.288 | 26.5 |
| 24 | -+-- | 88.42 | 85.1 | 0.412 | 26.5 |
| 25 | ++-- | 101.82 | 85.1 | 0.412 | 26.5 |
| 26 | +++- | 101.82 | 85.1 | 1.288 | 26.5 |

To Glossary ▶|

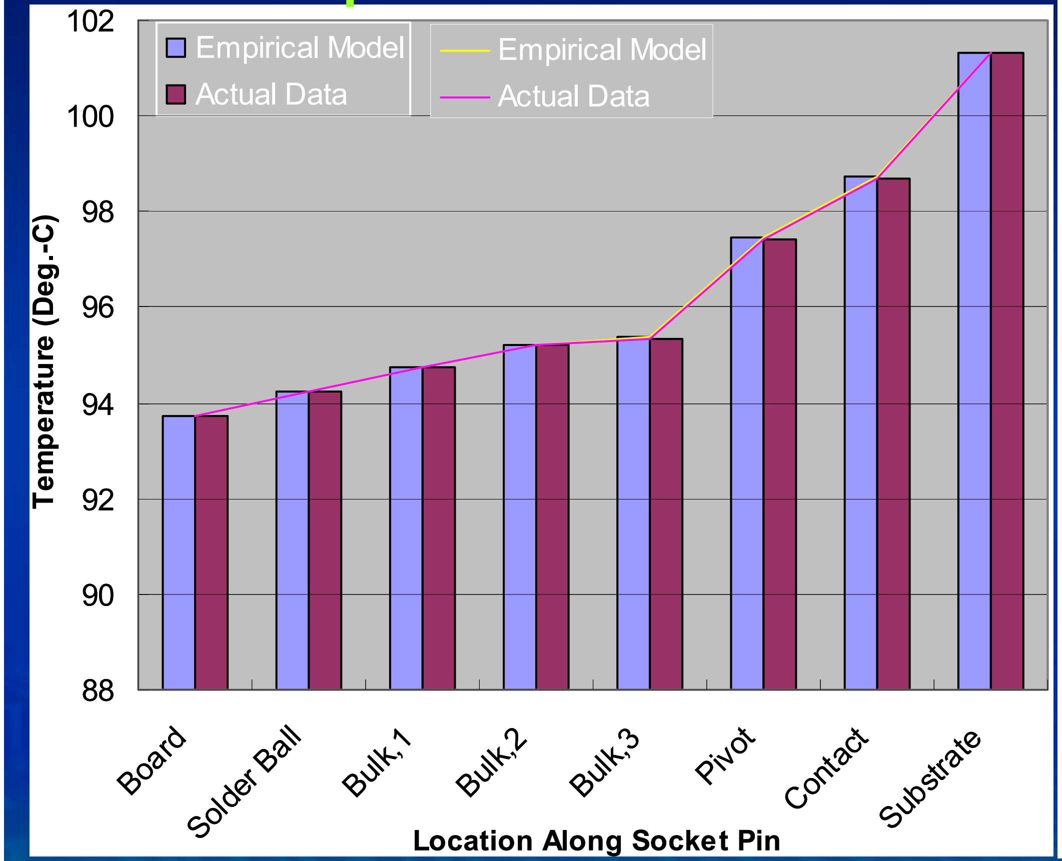
# Data Fitting: Empirical Model

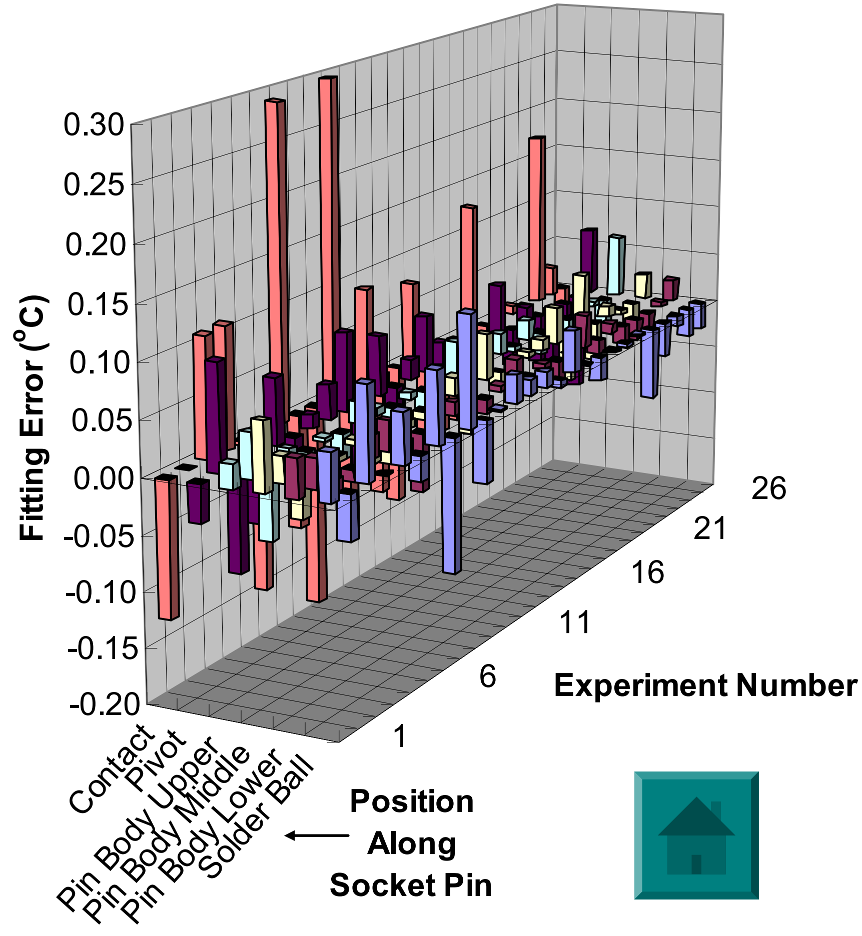
- At each of the 8 locations along the pin, perform a second-order polynomial fitting:
- $$\boxed{\begin{aligned} T_n = {} & c_{n,1}T_{sub} + c_{n,2}T_{board} + c_{n,3}P + c_{n,4}I_c \\ & + c_{n,5}T_{sub}^2 + c_{n,6}T_{sub}T_{board} + c_{n,7}T_{sub}P + c_{n,8}T_{sub}I_c \\ & + c_{n,9}T_{board}^2 + c_{n,10}T_{board}P + c_{n,11}T_{board}I_c \\ & + c_{n,12}P^2 + c_{n,13}P\,I_c \\ & + c_{n,14}I_c^2 \end{aligned}}$$

**$T_n$ : Temperature at location n,**
**$C_{n,\ 1\ldots14}$ : Fitting constants**
**$T_{sub}$: substrate temperature,**
**$T_{board}$: motherboard temperature**
**P: pressure, $I_c$ = pin current**

# Quality of Data Fitting

- A good fit between the measured data and the prediction model.



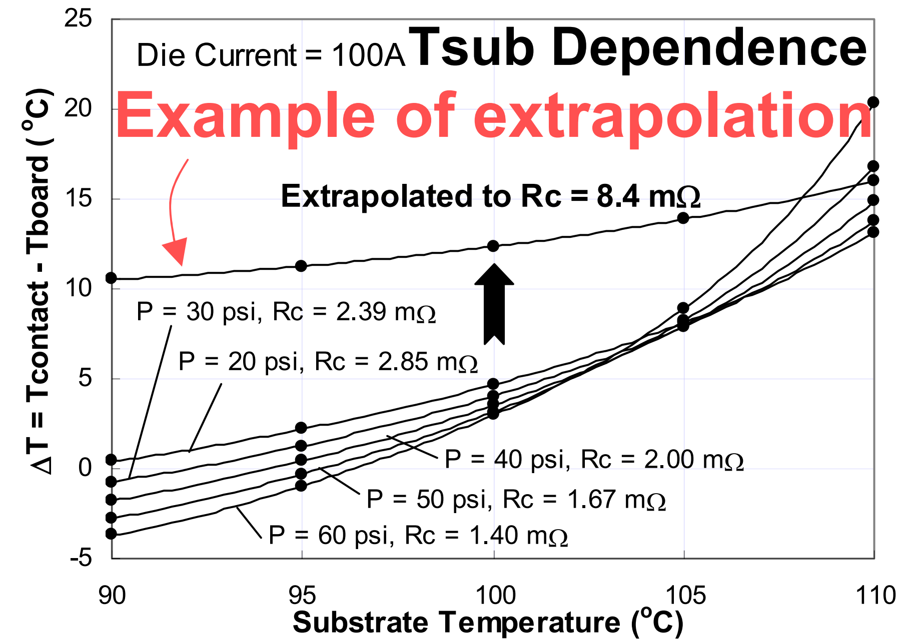


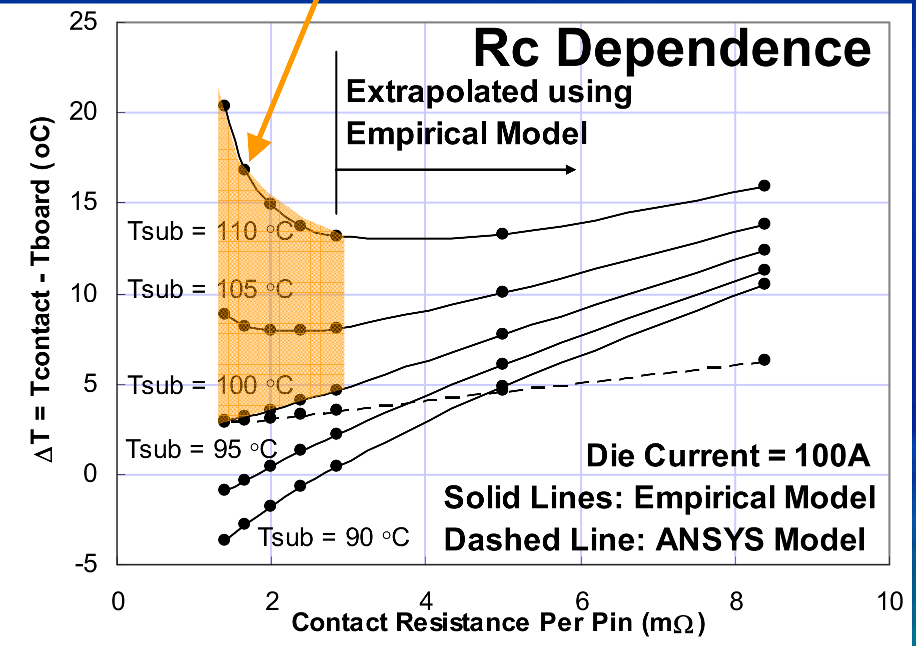
**Temperature Along Socket Pin: Sample Comparison – Good Fit**

**Fitting Error < ±0.3 °C for all cases**

# ΔT Prediction by Empirical Model

- ΔT has a ***strong depedence*** on both Tsub and Rc.
- At end-of-life, ΔT becomes less sensitive to Tsub
  Higher thermal Rc → Less heat flow from substrate to contact.
- ΔT generally increases with Rc
  Higher electrical Rc → More contact Joule heating.
- Exception: For Tsub > Tcontact, ΔT can increase with decreasing thermal Rc: More substrate-contact heat flow.


**Tsub Dependence**


**Rc Dependence**

- A large extrapolation of empirical model is used to obtain high contact resistance.

# Key Summary

- Infrared imaging has been successfully employed to measure the current carrying capacity (IMAX) of a microprocessor socket.
- A strategic DOE using multiple boundary conditions yielded a socket IMAX prediction model from the multi-dimensional data fitting. The prediction model fits the data within ±0.3 °C.
- Socket IMAX prediction model indicates that temperature drop across socket pin is a strong function of substrate temperature. This clearly shows that substrate effect cannot be ignored.
- Based on the experimental prediction mode, a revised numerical (FEM) model including substrate effect is in development.

To Glossary ▶|

# Glossary

DOE – Design of experiment
IMAX – Maximum current carrying capacity
IHS – Integrated heatsink
BKM – Best known Method
FEM – Finite element analysis
TC – Thermocouple
IR – Infrared
TV – Test vehicle,
i.e. a mock-up processor/ socket/board set.
DAC – Data acquisition and control
CCD – Central composite design

**To previously viewed slide**