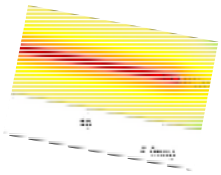
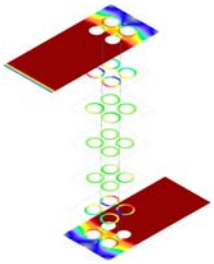
PNW Designer's Council, 5/4/16

PCB Trace and Via Currents and Temperatures:
The Story that Grew and Grew!





Doug Brooks, President ***UltraCAD Design, Inc.***

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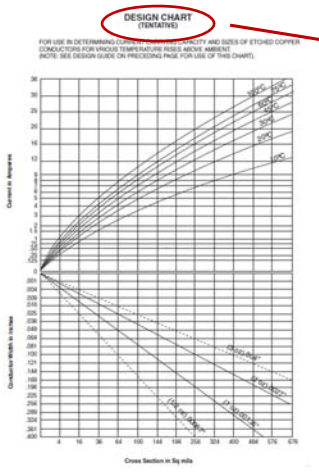
1

In The Beginning



DESIGN CHART
(TENTATIVE)

From: Natural Bureau of Standards Report # 4283, 1956

Authors labeled the report "Tentative" and asked for additional funding.

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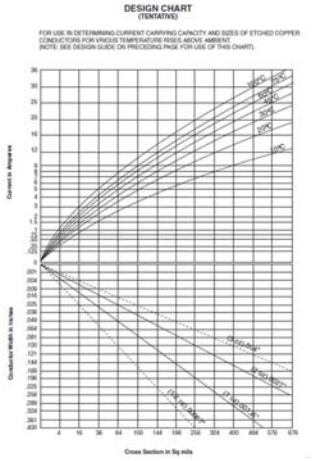
Two Charts



External traces:
empirically derived, poorly controlled

Internal Traces:
NOT empirically derived,
Derated from external trace data

They were guessed at!

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Reproduced:

MIL-STD-1495	**1973**
MIL-STD-275E	**1984**
IPC-D-275	**1991**
IPC-2221	**1998**
IPC-2221A	**2003**

These charts were our "Bible" until IPC-2152 was published in 2009.
And we got away with it!

Biggest surprise in IPC 2152 was that internal traces were *cooler* than external ones.

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Brooks' First Paper

First article was "Temperature Rise in PCB Traces," 1998

Compared two sources of data
- **Then current IPC data**
- **Data from Design News article, 1968**

DN data was 40% higher temperature

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Measuring Trace Temperatures, A

IPC (Change of Resistance) Method:

1. All *elements* have resistivity, ρ, (for copper it is 0.67 μOhm-in or 1.7 μOhm-cm)
2. R = ρ*L/A (so, ρ = R*A/L)
3. ρ changes with temperature (thermal coefficient of resistivity, α ≈.0038-.004)
4. ρ is always specified at a reference temperature (usually 20° C)
5. So, at some other temperature: $R(T) = R(T_o)*(1+ (\alpha_o*\Delta T))$
6. Therefore: $$\Delta T = \frac{1}{\alpha_0}\left[\frac{R_t}{R_{t_0}} - 1\right]$$

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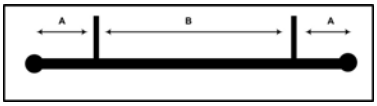
Measuring Trace Temperatures, A

IPC Test Method:



Two important observations:

1. **This measures the average temperature over the length of the test area.**
2. **This assumes we know α.**

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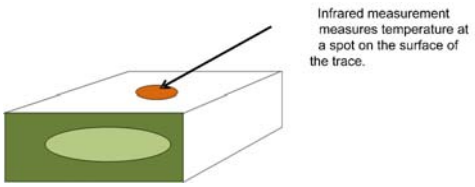
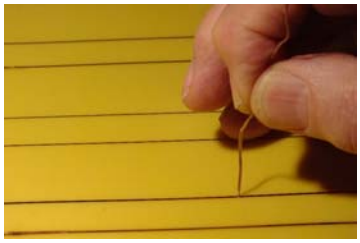
Measuring Trace Temperatures, B and C

B: Infrared Method (DN)



C: Thermocouple Method



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Searching for an Answer

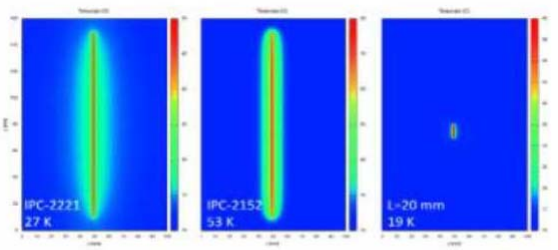

Figure1: Simulated thermographs of test boards with one powered trace (I=5 A). Left: a cladded bilayer PCB rises to ΔT=27 K above ambient, middle: single layer PCB rises to ΔT=53 K, right: a very short trace on a bilayer can be cooler than a long trace because front and end face contribute considerably to cooling (ΔT=19 K).

Saw this image in an article.

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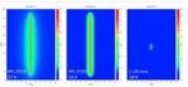
Searching for an Answer



Thermal Management of Boards and Current-Carrying Capacity of Traces

By: Johannes Adam

Appeared on:

http://www.powerguru.org/thermal-management-of-boards-and-current-carrying-capacity-of-traces/

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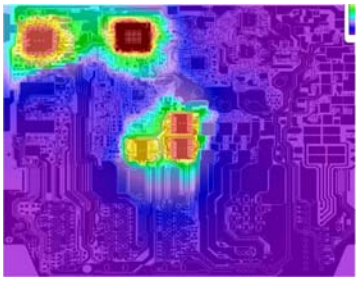
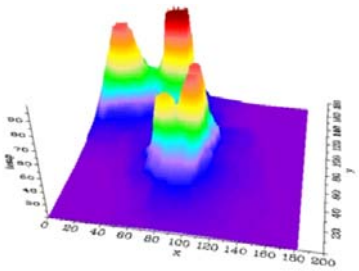
TRM

Thermal Risk Management

Written by Dr. Johannes Adam, Leimen, Germany

http://www.adam-research.de/





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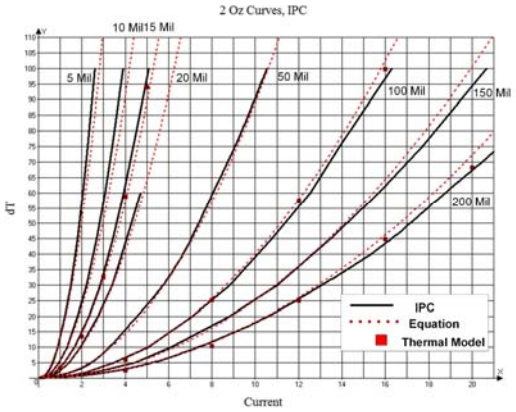
IPC Simulations



[Eq. 5.5] $\Delta T = 215.3 * C^{2} * W^{-1.15} * Th^{-1.0}$

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Sensitivity Analyses

Simulation Model	Temperature, Degree C	
	Basic Trace	Parallel or Adjacent
6″	69.2	
4″	68.0	
2″	60.9	
2″ w/sink (1)	59.3	
1″	49.0	
1″ w/sink (1)	46.3	
6″ gradient (2)	44.8	
w/Opposite Plane	54.1	43.3 (4)
w/Underlying Plane	45.9	44.7 (4)
Parallel Trace	62.0	55.0 (5)
Parallel + Plane	45.7	43.0 (5)
With Air Flow (3)	46.9	

Notes:
1. Heat sink under pads
2. Measured adjacent to pad.
3. *Very* approximate.
4. Adjacent plane maximum temperature
5. Adjacent trace maximum temperature

Basic trace is 100 mil wide, 6" long, and 1.5 Oz. thick, typically carrying 9.35 Amps.)

Two Conclusions:

1. **IPC data is "worst case"**
2. **Relationships are too complex to solve with equations and charts.**

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VIA Temperature !

Conventional Wisdom:

The cross-sectional area of a via should have at least the same cross-sectional area as the conductor or be larger than the conductor coming into it. If the via has less cross-sectional area than the conductor, then ***multiple vias*** *can be used to maintain the same cross-sectional area as the conductor. (emphasis added.)*

IPC 2152, p. 26

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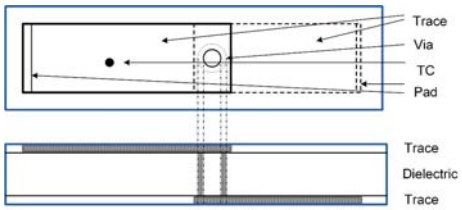
Via Model



Via is 10 mil dia., plated to 1.0 Oz. thickness.

Area is approximately equivalent to a 26 mil wide, 1.0 Oz trace.

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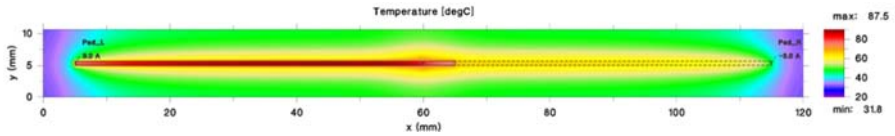
Simulation Results



For 26 mil trace, at a current of 3 Amps, temperatures are:

Trace	86.9° C
Via Top	81.4° C
Via Mid	80.9° C (*Cooler* than the trace.)

Changing trace width to 100 mils and current to 6 Amps;
Corresponding temperatures are:

Trace	61.8° C
Via Top	77.6° C
Via Mid	77.6° C (A little hotter than the trace.)

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Results

Keeping the (single) via size constant:

3 Amps with a narrow trace → 81° C
6 Amps with a wider trace → 78° C

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Conclusion:

It is not the current that determines the via temperature, it is the trace!

As long as the trace is sized correctly, only a single via is needed!

If there was ever a result that cried out:
"SHOW ME!"
this is it.

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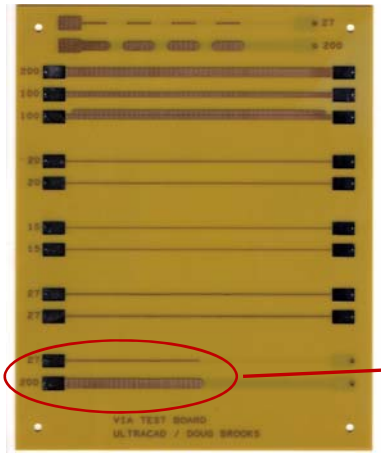
Via Test Board



Prototron Circuits generously offered to provide a test board.

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Via Results

	Width (mils)	Current (Amps)	Trace Temperature	Via Temperature
Measured	27	4.75	66.0	64.5
	200	8.55	40.5	44.5
Simulated	27	4.75	72.8	70.1
	200	8.55	44.8	48.1

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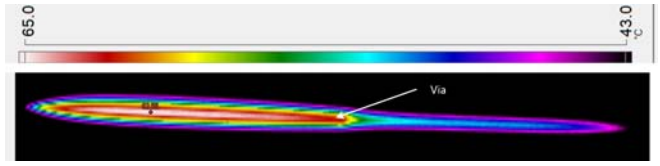
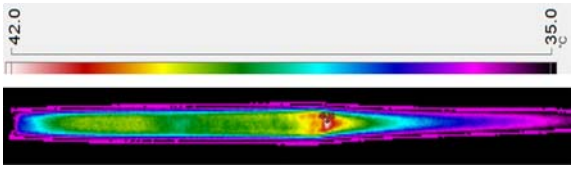
Thermographs

27 mil trace carrying 4.75 Amps.



200 mil trace carrying 8.55 Amps.



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Conclusion:

AGAIN: It is not the current that determines the via temperature, it is the trace!

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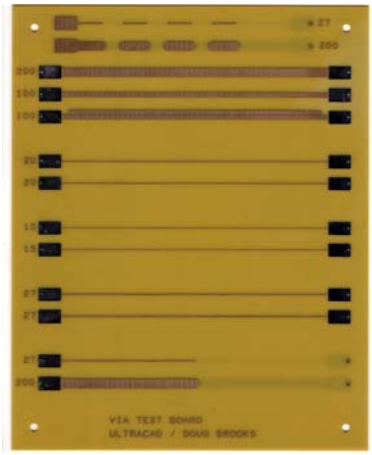
How This Story Grew, A



Measured *resistivity*:

Thickness variation

Web-based resistivity studies

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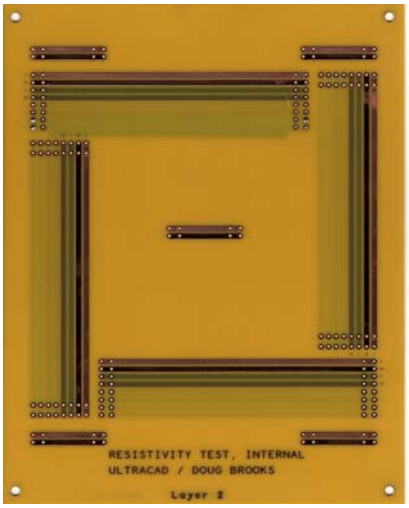
Resistivity Study

Foil thickness ≈ 2.0 mils
Plating Thickness ≈ 2.3 mils

Result: Appendix 2



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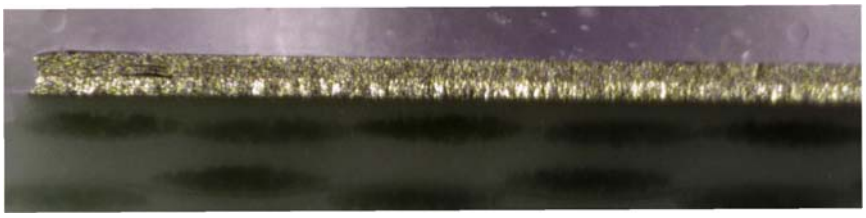
How This Story Grew, B

One major problem, thickness variation:

Is X-Ray an option?



One Oz. plating over a 0.5 Oz. Foil.

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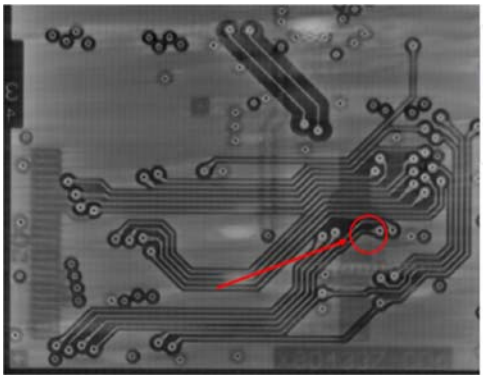
How This Story Grew, B

Thickness variation:

Jesse Garant Metrology Center, Windsor, Ontario



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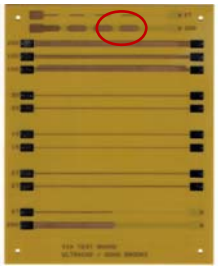
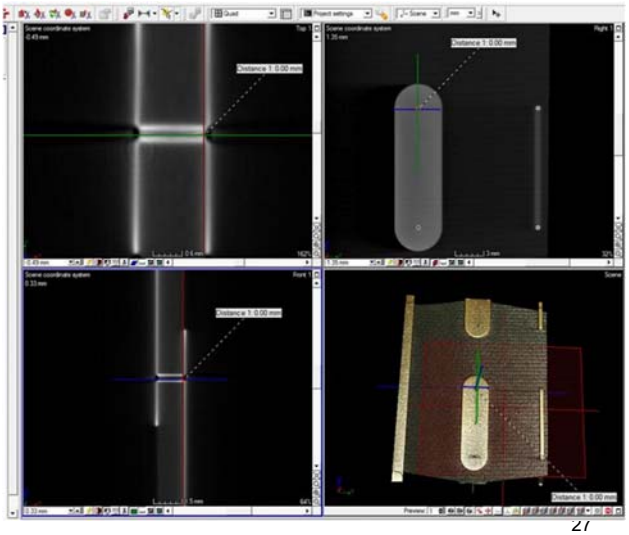
X-Ray Analysis





Result: Chapter 13

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How This Story Grew, C

Microscopy:

Nathanial Peters

W. M. Keck Center for Advanced Studies in Neural Signaling

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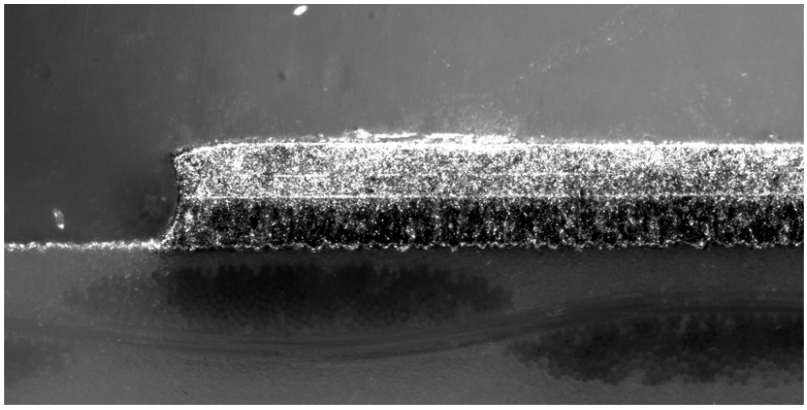
W. M. Keck Center



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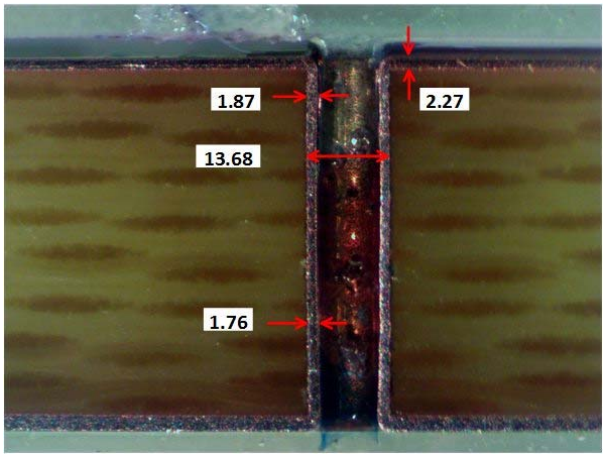
W. M. Keck Center



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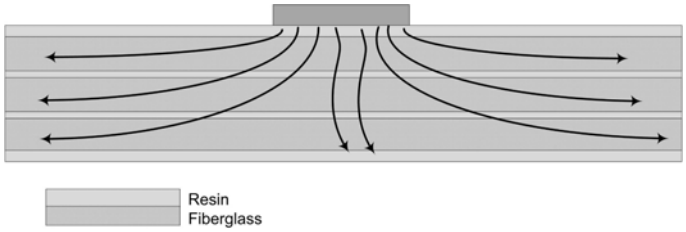
How This Story Grew, D

Via simulations were too high.

Traced reason to board *thermal conductivity* coefficient



C-Therm Technologies, Fredericton, New Brunswick

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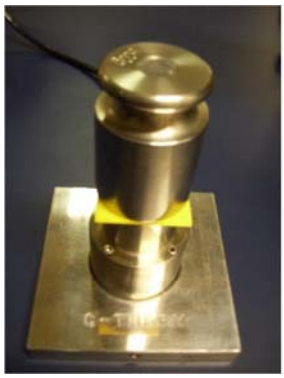
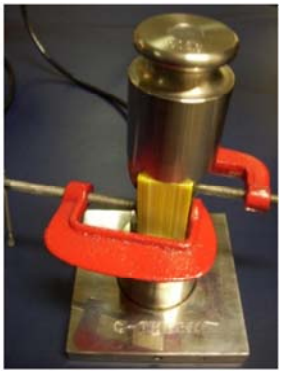
Thermal Conductivity Coefficient

C-Therm Technologies
Result: Appendix 1





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How This Story Grew, E

Thermal Conductivity analysis required special board -----

That allowed detailed *fusing studies* -----

Result: Chapter 11

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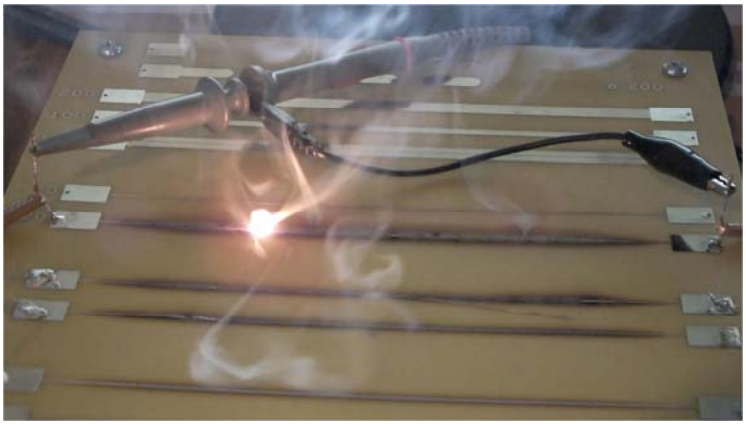
How This Story Grew, E



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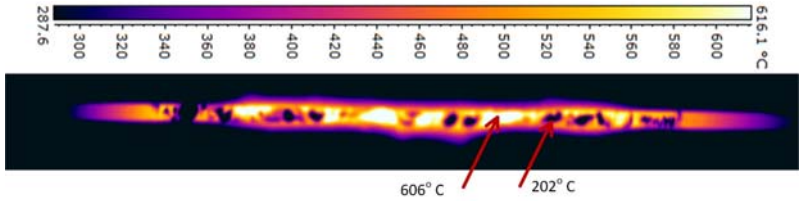
How This Story Grew, F

Hot Spots **on traces**

Norocel Codreanu, "Politechnica" University of Bucharest (Romania)



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Hot Spots on Traces

Need Thermal Imager

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Hot Spots on Traces

Thermal Imager

Scott Dau, Seattle firefighter

Result: Chapter 12

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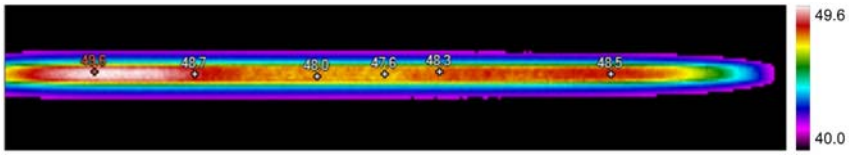
Hot Spots on Traces

Scott Dau, Thermal Imager
Result: Chapter 12



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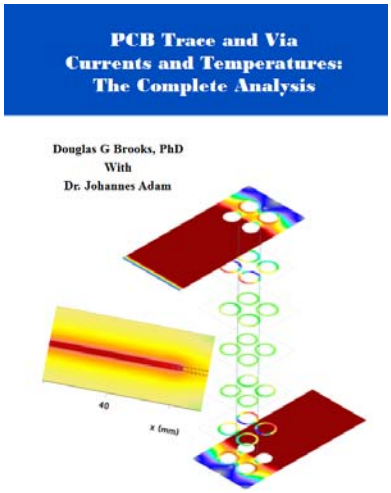
Result is a Book



To purchase a copy, go to:

http://www.amazon.com/author/dougbrooks

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Acknowledgements

Dave Graves (Monsoon Solutions, Bellevue)

C-Therm Technologies (New Brunswick, Canada)

Jesse Garant Metrology Center (Windsor, Ontario)

Nathanial Peters, W. M. Keck Center for Advanced Studies in Neural Signaling

Norocel Codreanu, Romania

Scott Dau, Seattle Firefighter, Part-time Fire Investigation Instructor

Prototron Circuits

Johannes Adam, Liemen, Germany

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What's Next?

A study of AC currents……

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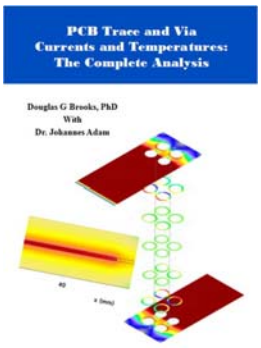
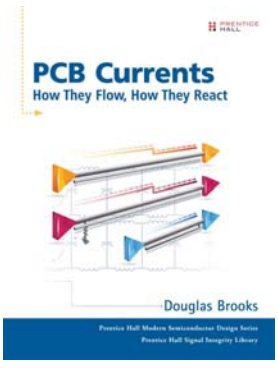
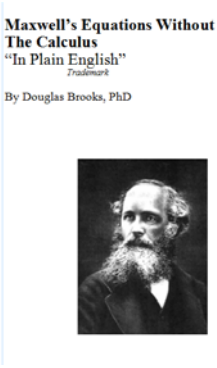
Books

Books by Doug Brooks you may find interesting:







Purchase them at http://www.amazon.com/author/dougbrooks

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Thanks for attending