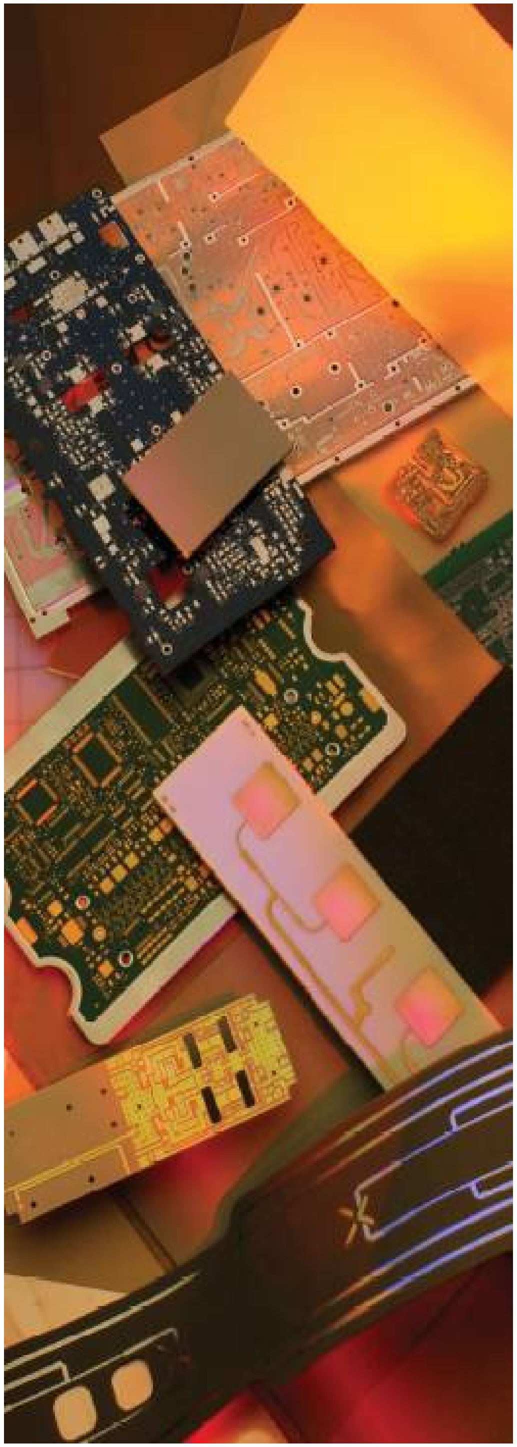
IWPC - Enclosure and Cooling Technologies for Outdoor Base Stations



Expanding the Thermal Management Tools for RF Base Stations –
Low Loss Thermally Conductive PTFE Laminates

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Who is Arlon?

- 50+ years in microwave substrates
- First Commercial Sale of PTFE Laminate (62 mils thick DiClad 522 to Collins Radio in 1939 *(Rockwell-Collins)*
- 35+ years experience making Polyimide & Specialty Epoxy Laminates for high reliably applications
- Purchased 3M Microwave Line in 1987 (CuClad)
  - First manufacturer to disperse ceramic into PTFE (Epsilam 10) in the early 1970's
- Launched thermally conductive FR4 (99ML) in 2005 & has continued to expand this technology

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ARLON Electronic Materials
Global Manufacturing Locations

Bear, DE
Group HQ

Rancho Cucamonga, CA

Suzhou, China

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Thermal Management Drivers

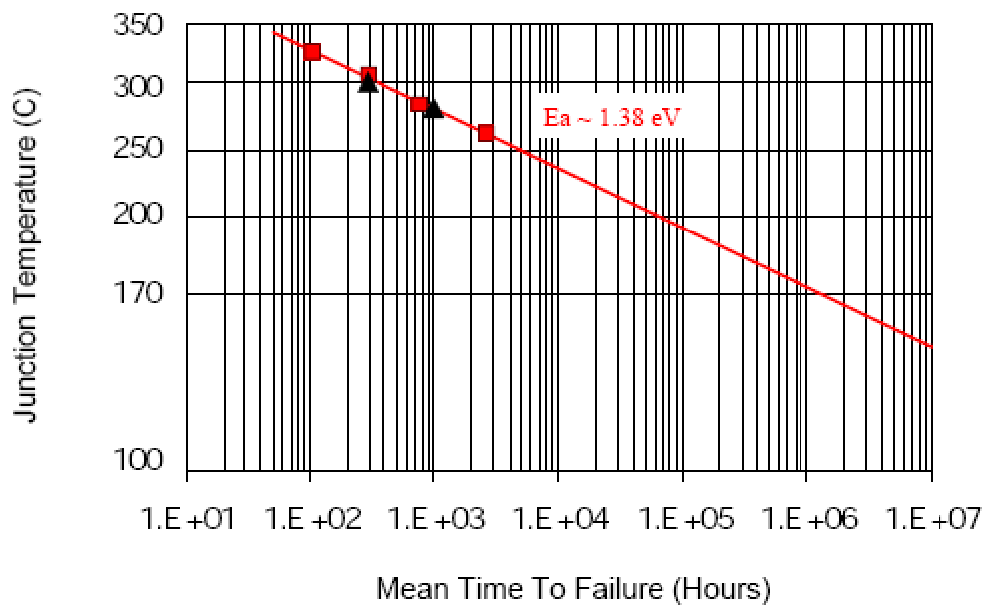
- Power density continues to increase
- Packaging getting smaller & hotter
- Higher temperatures reduce component reliability
- Tower mounted & outdoor electronics increase environmental exposure while requiring higher reliability
- Complex waveforms decrease amplifier efficiency, more energy lost to heat

The Cost of Failure

- Typical Amplifier Failure Pareto
  - Generally, Component Failures account for 70 to 90% of returns
- A single sector failure of 2 hours can result in $2,000 lost revenue to service provider
- In poor weather conditions, downtime can be 20 to 28 hours => $25,000 lost revenue

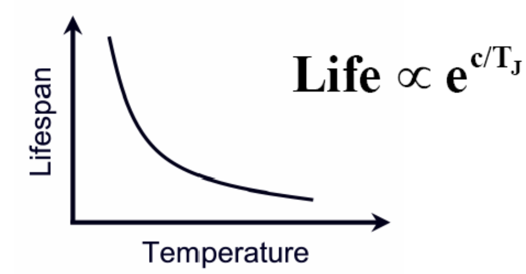
Why is Thermal Management Important?

HV HBT Reliability – Arrhenius Chart



Eli Reese, TriQuint
IWPC November 2005

Reliability of components follows a first order Arrhenius equation:
10°C increase doubles failure rate



Even 1°C matters

Traditional Thermal Management Options

- Heavy Metal Backplanes *(IWPC-Munich, Dec 2006, Albert Angstenberger, Taconic)*
- Thermal Vias
- Thermal Coins *(IWPC-Munich, Dec 2006 and Dulles, June 2007, Art Aguayo, Rogers)*
- Heat Sinks, Heat Spreaders, Heat Risers *(IWPC-Munich, Dec 2006, Pekka Rintala, GrafTech)*
- Thermally Conductive Adhesives, Gap Fillers, Grease, etc.
- Active Cooling – Forced Air, Conditioned Air
- Water Cooled, Vapor Cooled, direct, indirect

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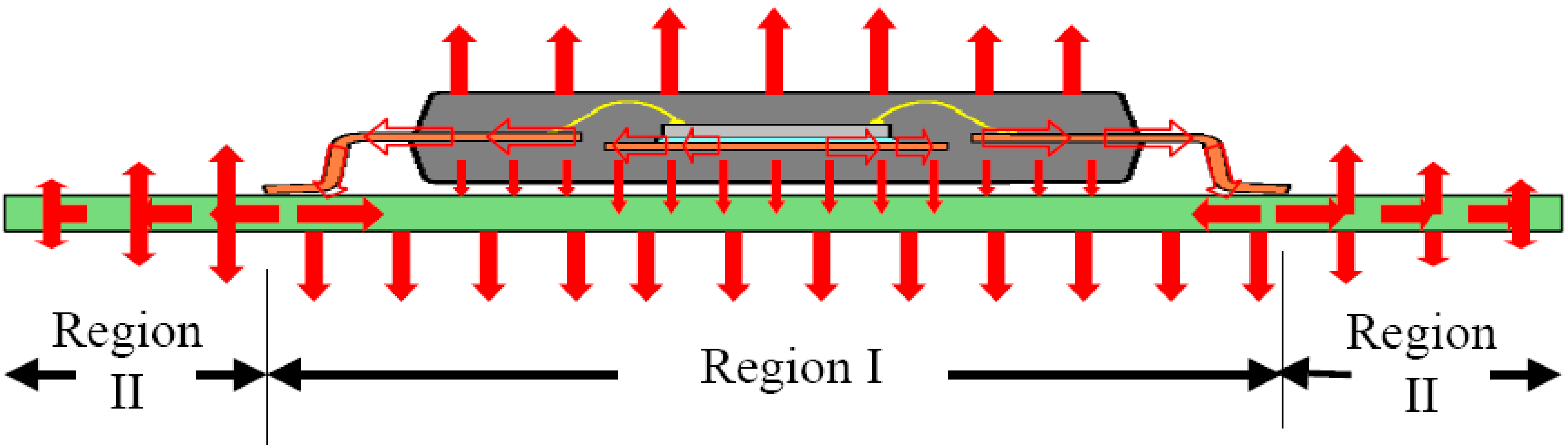
RF/Microwave Design Implications

- Limitations with Thermal Vias – Signal Integrity, Dielectric Variation if near signal trace, etc.
- Cost of heat sinks & heat spreaders (3 mm copper plate can add over $25/board)
- Thermal coins, cut-outs increase fabrication & assembly complexity & costs
- Forced convection systems increase costs & add to reliability concerns

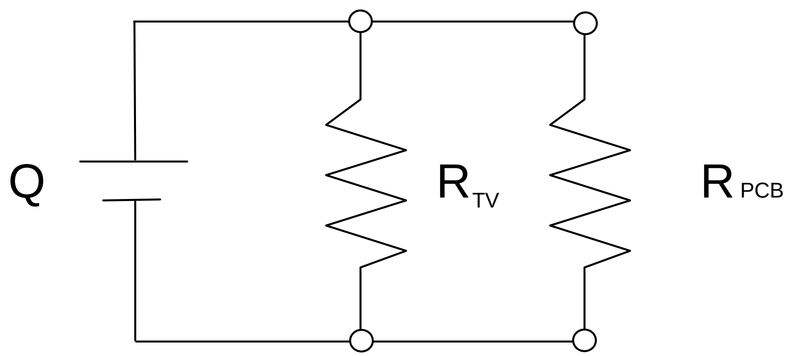
Thermal Modeling

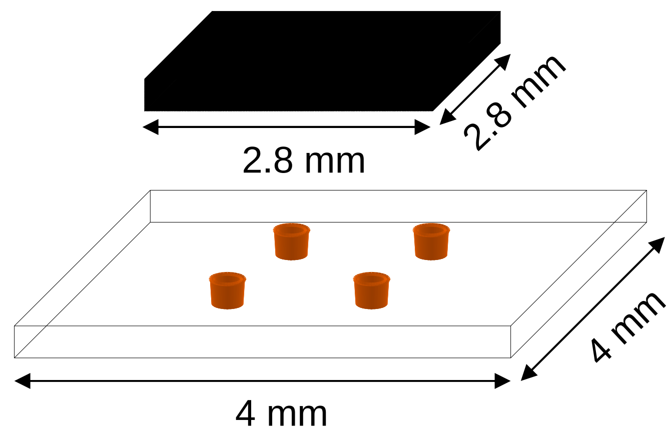


Conductive and radiative heat transfer in a standard thermal test environment allow for analytical expressions

Bruce M. Guenin, Electronics Cooling, Sept. 1998

Simplified Heat Transfer Example





$$Q = \Delta T\left(\frac{1}{R_{TV}} + \frac{1}{R_{PCB}} + \ldots\right)$$

$$R_{TV} = n \cdot L \cdot TC \cdot \pi\left(\frac{1}{R_o^{\,2}} + \frac{1}{R_I^{\,2}}\right)$$

Model Assumptions:

4mm x 4mm part mounted on a 0.031" PC Board
4 Vias using 0.014" (0.35mm) drill
Finished Size is 0.010" (0.25)
Plating Thickness of 0.001" (0.025mm)
n = Number of Vias (4)
TC = thermal conductivity of copper (390 W/(m°C))
L = Board Thickness (length of PTH)
Q = 3.4 Watts of power to be dissipated
Enclosed Device (convection => 0)

R_{TV} = 20°C/W

Thermal Management Options

- Heavy Metal Backplanes *(IWPC-Munich, Dec 2006, Albert Angstenberger, Taconic)*
- Thermal Vias
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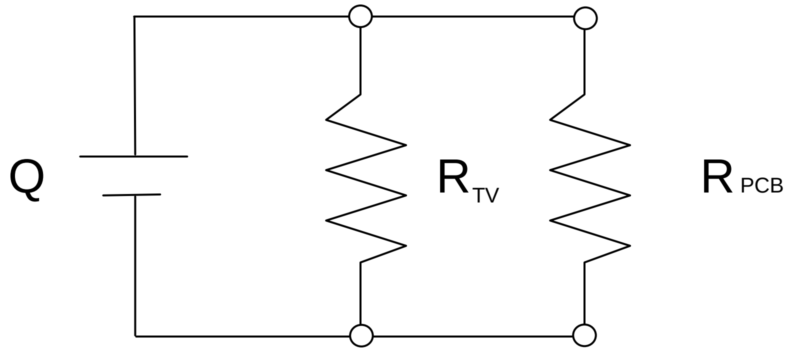
- Thermally Conductive Adhesives, Gap Fillers, Grease, etc.
- Active Cooling – Forced Air, Conditioned Air
- Water Cooled, Vapor Cooled, direct, indirect
- Increased Thermal Conductivity of Microwave Laminate

Simplified Heat Transfer Example



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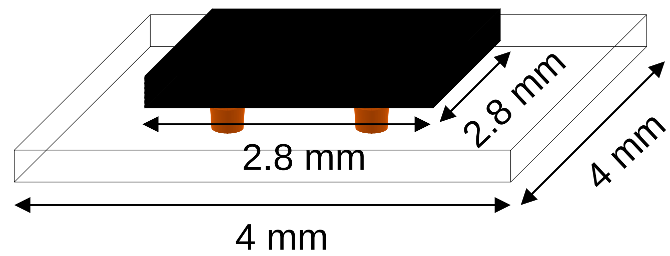

Board Thermal Conductivity (W/mK)	Resulting Heat Rise °C (T_{max}-$T_{operating}$)
0.2	65.4
0.4	62.7
0.6	60.0
0.8	57.3
1.0	54.6
1.2	51.9

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Other Considerations

- Simple model neglects secondary benefits of improved heat spreading with higher substrate thermal conductivity
  - increases effective heat transfer area
  - improves efficiency of other heat transfer mechanisms such as forced convection systems, heat sinks or additional thermal vias
- Benefits of substrate thermal conductivity increases with high power, higher frequency designs
- Increased heat capacity associated with select ceramic fillers provides some heat sink benefits
- At constant heat rise, the improvement in heat transfer can be used to increase power handling 5-10%

Thermally Conductive Development Objectives

- Maintain Current Material Cost Structure
- Improve Dielectric Loss (loss tangent) and Insertion Loss to reduce heat generation
  - 3.5 & 6.15 Dk material targets to match predominant industry RF amplifier designs
- Increase Base Laminate Thermal Conductivity *(cross-plane and in-plane conductivity)* to reduce resistance to heat transfer
- Maintain Laminate Integrity
  - Copper adhesion
  - Moisture absorption

Project Results – Arlon's TC600 Laminate

Key Properties	**TC600**	AD600	Competitor B	Competitor A
Dk (@ 10 GHz)	6.15	6.15	6.15	6.15
Df (@ 10 GHz)	0.0022	0.003	0.003	0.0027
Thermal Conductivity	**1.1**	**0.46**	**0.43**	**0.63**
CTEx,y	8	10-11	11-13	13-14
CTEz	17	45	75	47
Copper Peel	8	10	8	7
Moisture Absorption(%)	0.01	0.04	0.02	<0.1

- Improves heat-transfer within the PCB by 2-3x alternative materials
- Currently being commercially released

Development Results – Arlon's TC350 Laminate

Key Properties	**TC350**	AD350A	Competitor B	Competitor A
Dk (@ 10 GHz)	3.50	3.50	3.50	3.48
Df (@ 10 GHz)	0.0025	0.003	0.003	0.0037
Thermal Conductivity	**0.80**	**0.45**	**0.35**	**0.65**
CTEx,y	8	5, 9	8, 10	14, 16
CTEz	17	35	29	35
Copper Peel	8	17	> 10	5
Moisture Absorption(%)	0.01	0.1	0.04	0.06

- Improves heat-transfer within the PCB by ~2x alternative PTFE materials
- Expected to be commercial 4Q2007

Arlon Proprietary Technology

- Through unique chemistry and processing, Arlon has been able to develop two unique, thermally conductive laminates
- TC600 doubles the thermal conductivity of existing materials in the 6 DK market while achieving very low loss (0.0022 at 10 GHz via IPC TM-650 2.5.5.5 Test)
- TC350 increases thermal conductivity by nearly 50% in the 3.50 Dk market while achieving very low loss (0.0025 at 10 GHz via IPC TM-650 2.5.5.5 Test)

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Conclusions

- Tradition laminates provide the greatest resistance (insulation) to heat transfer
- Increasing thermal conductivity is new to the RF tool kit with negligible expected cost implications or impact on signal integrity
  - Improved reliability
  - Improved power handling
  - Complements existing thermal management tools
- TC600 Product is currently being commercialized (launched). Beta Site Tested.
- TC350 still requires production qualification, but should be feasible based on current results. Beta Sampling expected in August/September 2007
- Project objective to maintain current costs while improving performance offer designers additional options with minimal concerns or risk

Wish List

- Improved understanding of value of improved heat transfer & impact on reliability
- Better understanding of system trade-offs of alternative thermal management tools in RF applications
- Happy Customers