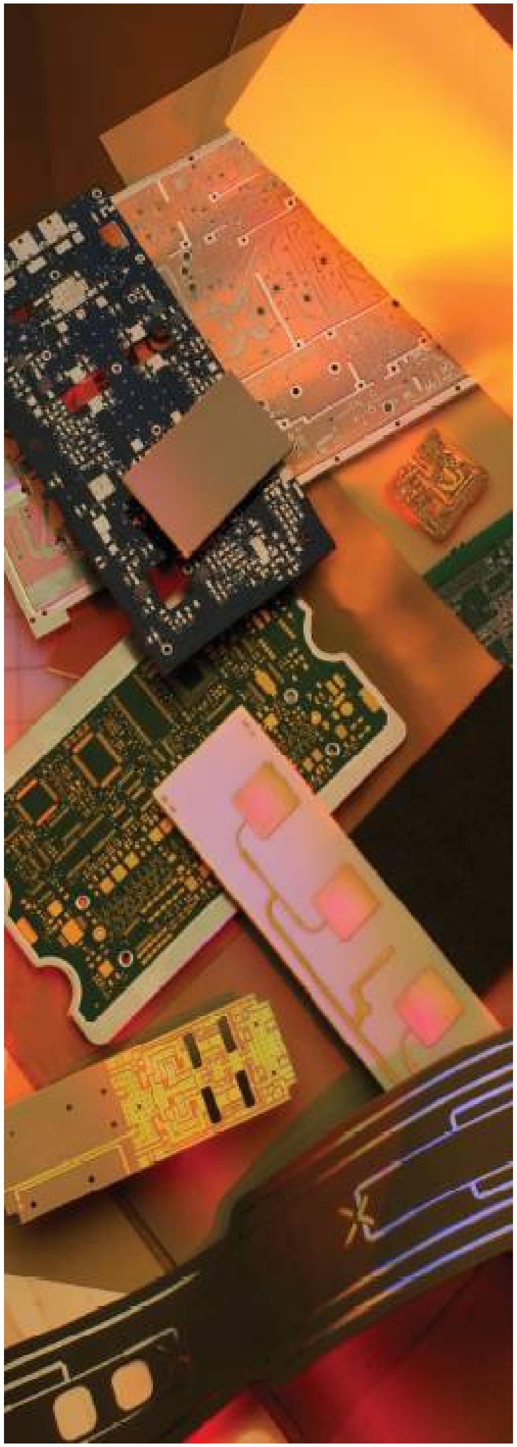


IWPC - WiMAX, LTE and UMB Infrastructure RF Technology Challenges

Expanding the Thermal Management Tools for RF Infrastructure & Power Amplifiers –

Low Loss Thermally Conductive PTFE and Thermally Conductive FR-4 Laminates

Oct 18, 2007

Russell Hornung
Technical Marketing Manager
rhornung@arlon-med.com

ARLON
TECHNOLOGY ENABLING INNOVATION

Who is Arlon?

- Origins start in 1895 in Newark, DE as Continental-Diamond Fibre, (bought by Budd Co then sold to Keene. Spun-out as Arlon in 1990)
- 55+ years in microwave substrates
- First Fluoropolymer Processor outside of DuPont (1949) *(President Norris Wright was a close friend of a DuPont VP)* *
- First Commercial Sale of PTFE Laminate (62 mils thick DiClad 522 to Collins Radio in 1949 *(Rockwell-Collins)*
- Purchased 3M Microwave Line in 1987 (CuClad)
  - First manufacturer to disperse ceramic into PTFE (Epsilam 10) in the early 1970's
- 35+ years experience making Polyimide & Specialty Epoxy Laminates for high reliably applications – origins Howe Industries
- Launched thermally conductive FR4 (99ML) in 2005 & have continued to expand this technology. Soon to Launch 91ML and 92ML

* *Society of Plastics Industry - Fluoropolymers Division*

ARLON Electronic Materials

Global Manufacturing Locations

Bear, DE
Group HQ &
Manufacturing

Rancho Cucamonga, CA

Suzhou, China

Thermal Management Drivers of RF Infrastructure

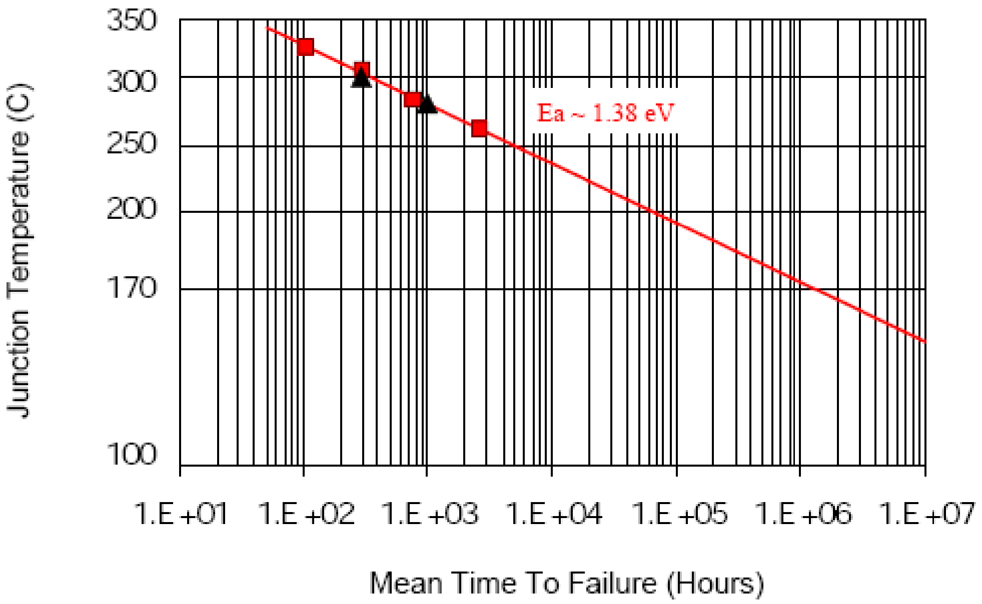
- Power density continues to increase
- Packaging getting smaller & hotter
- Tower mounted & outdoor electronics increase environmental exposure while requiring higher reliability
- Complex waveforms decrease amplifier efficiency, more energy lost to heat
- Higher temperatures reduce component reliability

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 €1,450 ($2,000) lost revenue to service provider
- In poor weather conditions, downtime can be 20 to 28 hours => €18,000 ($25,000) lost revenue

Why is Thermal Management Important?

HV HBT Reliability – Arrhenius Chart



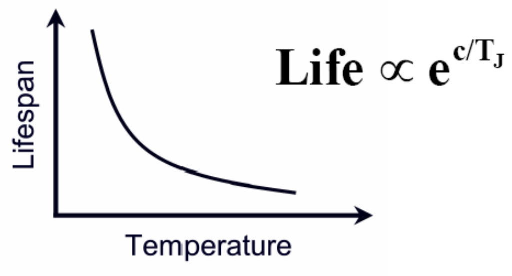
1-Nov-05
6

TriQuint SEMICONDUCTOR

Eli Reese, TriQuint
IWPC November 2005

Reliability of components follows a first order Arrhenius equation:

10°C increase doubles failure rate



$$\text{Life} \propto e^{c/T_J}$$

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

RF/Microwave Design Implications

- Limitations with Thermal Vias – Signal Integrity, Dielectric Variation if near signal trace, Mechanical & Physical Robustness, etc.
- Cost of heat sinks & heat spreaders (3 mm copper plate can add over €18 ($25) per board
- Thermal coins, cut-outs increase fabrication & assembly complexity & costs
- Forced convection systems increase costs & add to reliability concerns

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
- Increased Thermal Conductivity of Microwave Laminate

What benefit does Laminate Thermal Conductivity offer to the RF Infrastructure Market?

- Component and Solder Joint Reliability improvements would drive down warranty costs
- At constant heat rise, the improvement in heat transfer can be used to increase power handling 5-10%
- Thermal Stability of Dielectric Constant reduces *"Dead Bandwidth"*, increases phase stability over temperature, reduces design limits & complexity
- Compliments all other alternative sources of thermal heat extraction …. ***Doesn't cost you anything!!!***
- Or potentially simplifies or lowers costs of other thermal solutions ***(i.e. cast vs. machined heat sinks, reduction in copper plate thickness from 3mm to 1mm)***

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 Dielectric Constant (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

Arlon Proprietary Technology

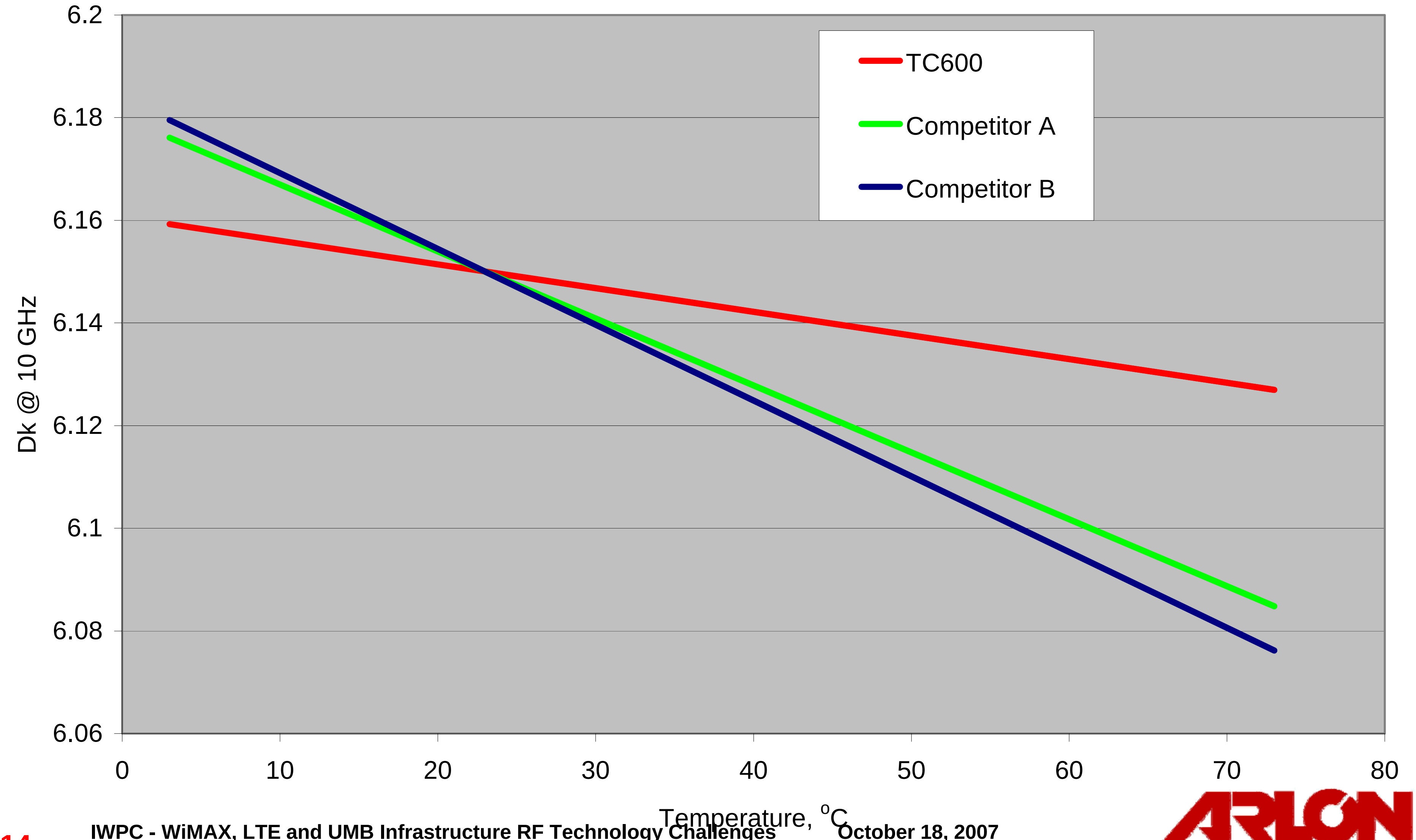
- Through unique chemistry and processing, Arlon has been able to develop two unique, thermally conductive laminates
- **TC600** doubles the thermal conductivity of existing materials in the 6 DK market while achieving very low loss (0.0022 at 10 GHz via IPC TM-650 2.5.5.5 Test)
- **TC350** increases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

Project Results – Arlon’s TC600 Laminate

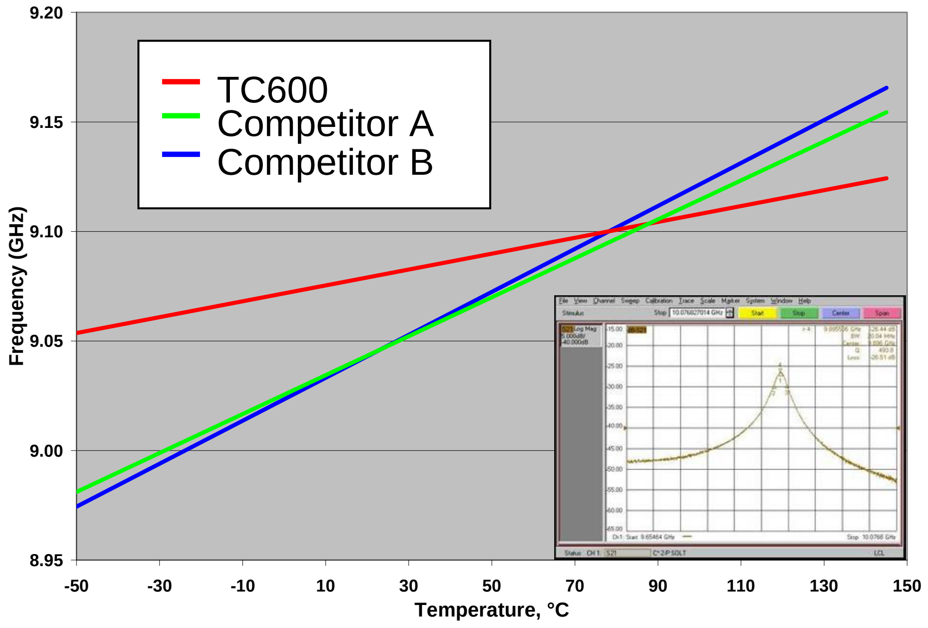
Key Properties	**TC600**	AD600	Competitor B	Competitor A
Dk (@ 10 GHz)	6.15	6.15	6.15	6.15
Df (@ 10 GHz)	0.0022	0.003	0.003	0.0027
Thermal Conductivity (z)	**1.1**	**0.46**	**0.43**	**0.63**
Thermal Conductivity (x,y)	**1.4**	**???**	**???**	**???**
CTEx,y	8	10-11	11-13	13-14
CTEz	17	45	75	47
Copper Peel	8	10	8	7
Moisture Absorption(%)	0.01	0.04	0.02	<0.1

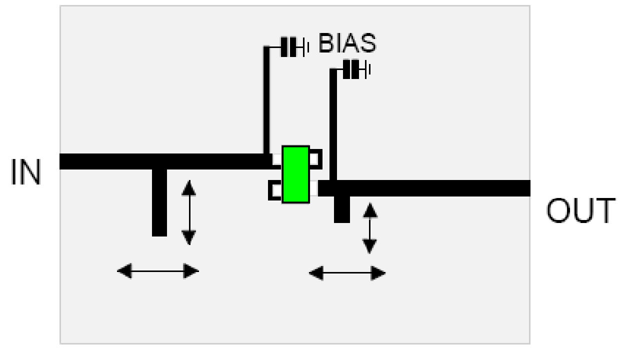
- Improves heat-transfer within the PCB by 2-3x alternative materials
- Currently being commercially released

Temperature Sensitivity to Dielectric Constant



Temperature Sensitivity of Resonance Frequency





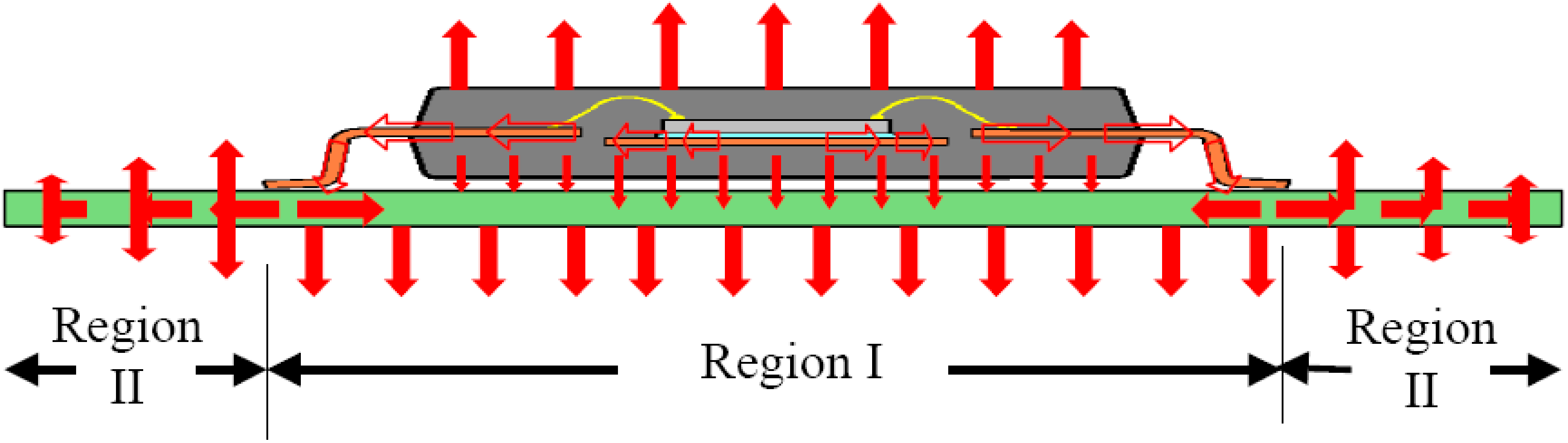
- Insensitive Materials Help Power Amplifier and Antenna designers minimize dead bandwidth which is lost to dielectric constant drift as operating temperature changes
- For antenna designs, a significant shift in Resonance Frequency and bandwidth roll off at specific frequencies, results in lower gain performance
- Thermal stability feature is critical to phase sensitive devices such as impedance network transformers utilized for matching networks of power amplifiers

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 (Z- Direction)	**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 Beta sampled in 4Q2007

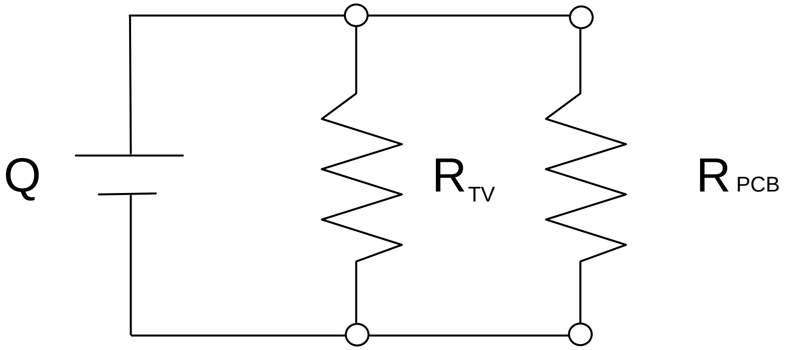
Thermal Modeling Efforts

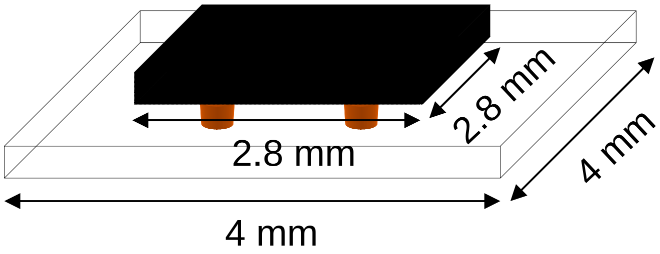


Conductive and radiative heat transfer in a standard thermal test environment allow for analytical expressions

Bruce M. Guenin, Electronics Cooling, Sept. 1998

Value of Higher Laminate Thermal Conductivity





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

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

Model Assumptions:

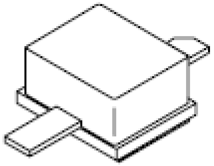
4mm x 4mm part mounted on a 0.031" PC Board
4 Vias using 0.014" (0.35mm) drill
Finished Size is 0.010" (0.25)
Plating Thickness of 0.001" (0.025mm)
n = Number of Vias (4)
TC = thermal conductivity of copper (390 W/(m°C))
L = Board Thickness (length of PTH)
Q = 3.4 Watts of power to be dissipated
Enclosed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

R_{TV} = 20°C/W

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**

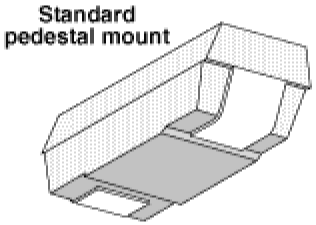
Two Test Circuits – 0.025” Laminate Thickness

- 2000 MHz, 10 W, 26 Volts, RF Power MOSFET, 0.0355” Trace Width



freescale™ semiconductor

- Two Ohmite Power Resistors, 47 Ohms, 0.6 Watt each, Wirewound Surface Mount Power, 0.0355” Trace Width, 0.700” between centers.   9 Volts DC applied to Trace



OHMITE®

* *Arlon implies no preference in components.   Chosen for availability, historical familiarity and reliable reputation*

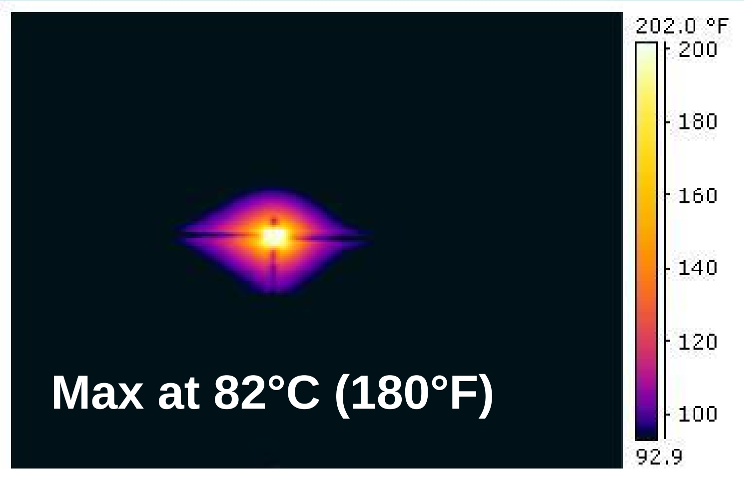
RF Power Field Effect Transistor

Heat spreading associated with TC600 is related to higher TCxy vs TCz

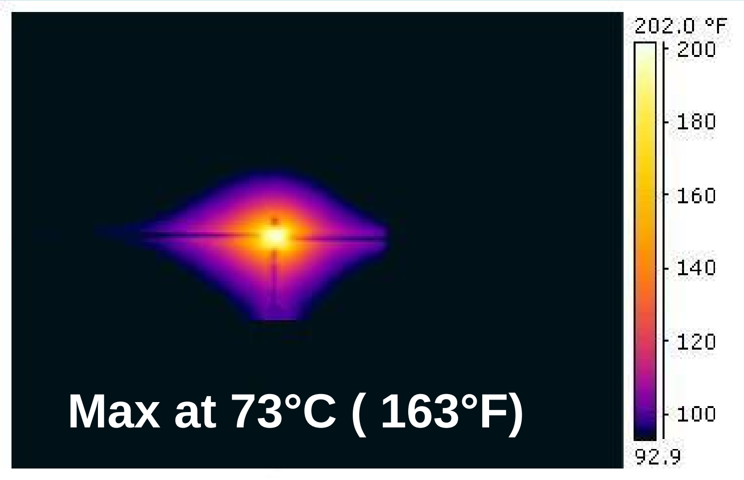
Alternative (TCz = 0.46)

TC600 (TCz = 1.1)

Top

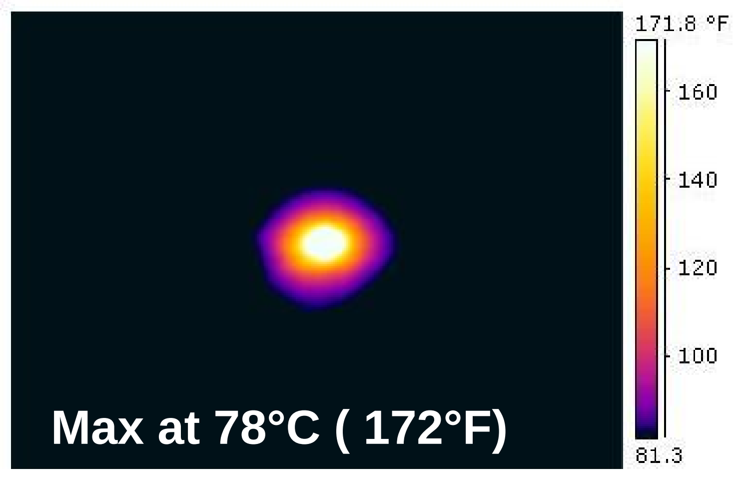


Max at 82°C (180°F)

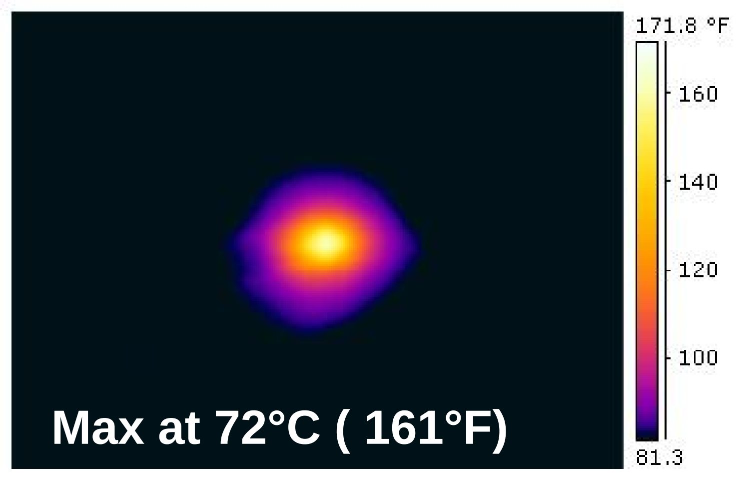


Max at 73°C (163°F)

Bottom



Max at 78°C (172°F)



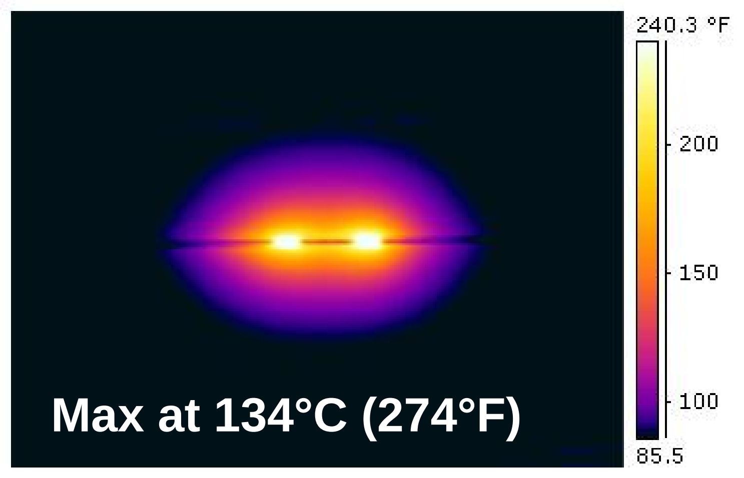
Max at 72°C (161°F)

Two 47 Ohm Power Resistors

Heat spreading associated with TC600 is related to higher TCxy vs TCz

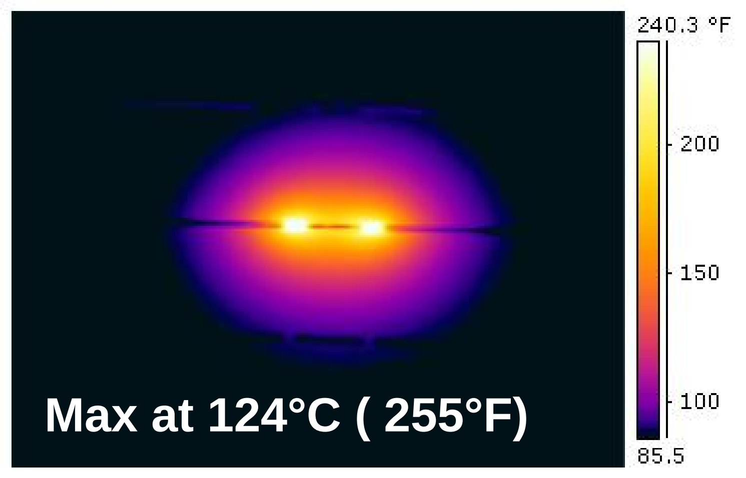
Alternative (TCz = 0.46)

TC600 (TCz = 1.1)

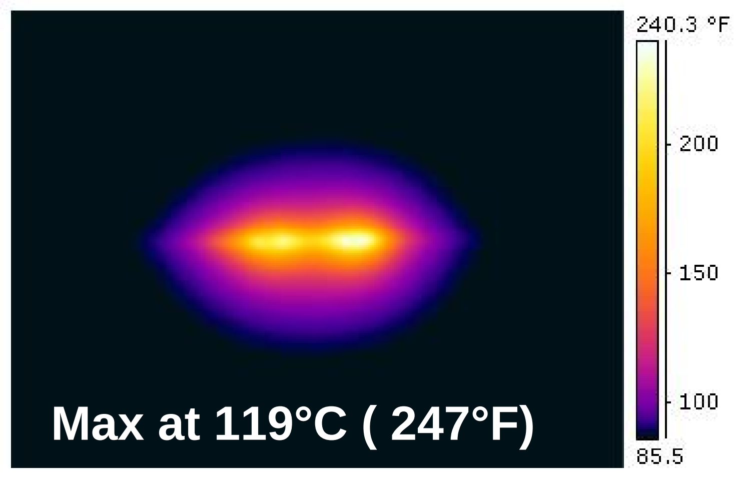


Max at 134°C (274°F)

Top

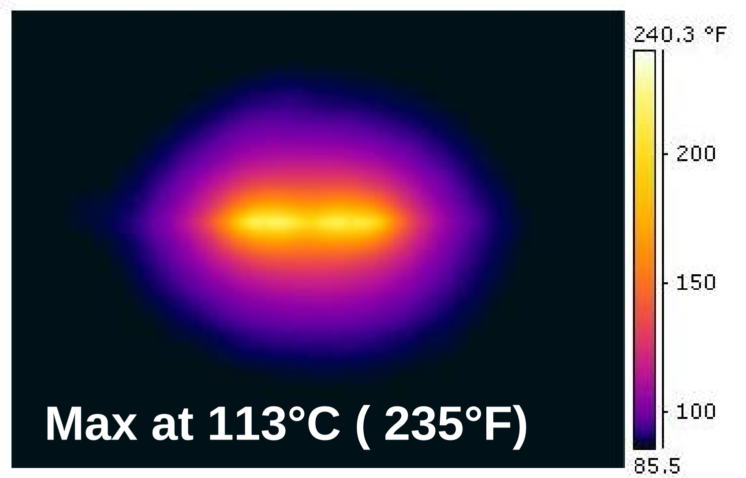


Max at 124°C (255°F)



Max at 119°C (247°F)

Bottom

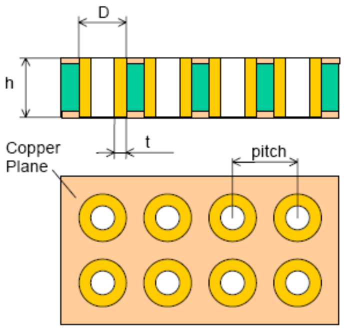


Max at 113°C (235°F)

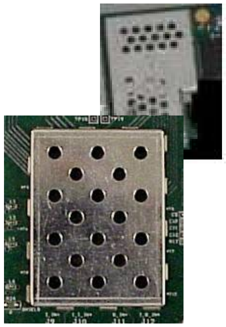
Application Specific Feedback

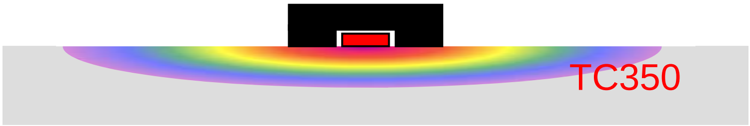
- Thermal Vias are able to reduce Temperature 20°C on a specific 160 Watt MCPA
- Doubling Thermal Conductivity will further reduce junction temperature 5°C compared to an incumbent material for a specific application
- EMI shielding can increase temperatures in excess of 15°C. Natural Convection or chip mounted heat sink is not always a physical option
- Higher Thermal Conductivity would eliminate need for more costly alternative heat sink with higher thermal conductivity

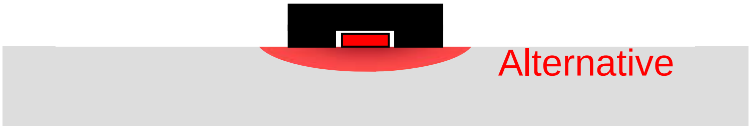
Thermal Vias



EMI Shielding

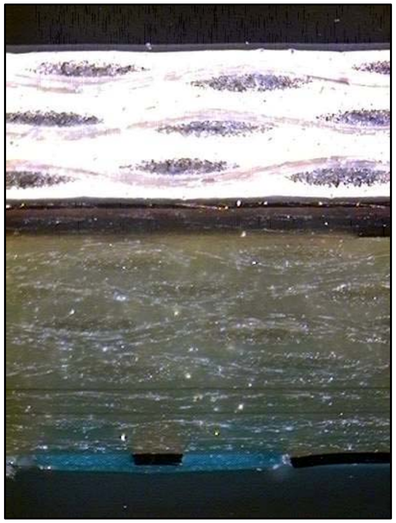






Why in an RF Forum would there be interest in Higher Thermally Conductive FR-4 ??

- Hybrid Boards of Low Loss RF Material combined with FR-4 is common
- RF functions utilize the Low Loss layer and digital functions are segregated to the FR-4 layer
- Need for High Temperature, Low CTEz, High Decomposition Temperature, *"Lead Free Solder Process Friendly"* Pre-Preg with good electrical strength, available as a thin pre-preg (low thermal resistance)

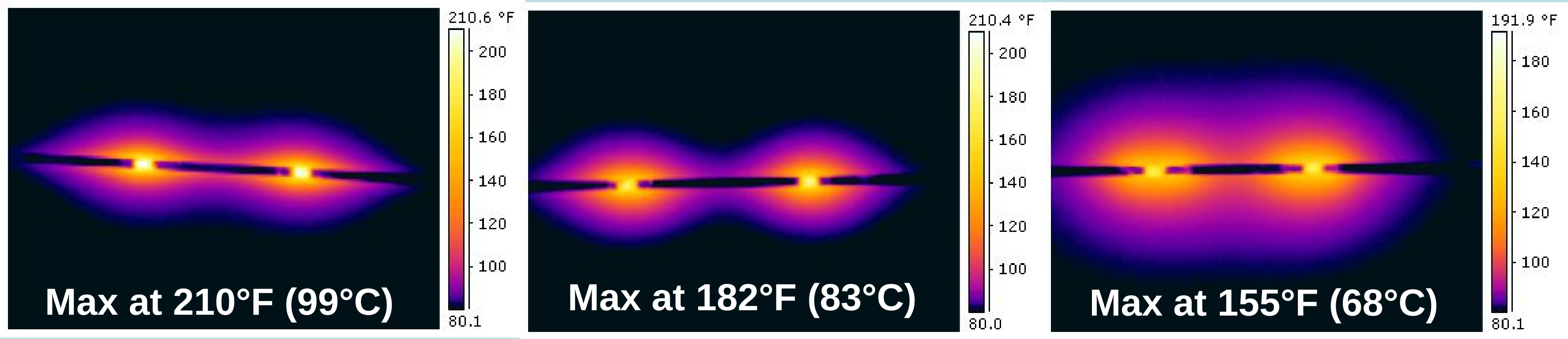


THERMALLY CONDUCTIVE FR4

- Two laminate & prepreg systems are underdevelopment as next generation materials to the Arlon 99 Series
  - 91ML targets a low-cost, 1 W/mK, (Z-direction) lead-free epoxy system
  - 92ML targets a high performance lead-free free system.
    - 2 W/mK (Z-direction)
    - 4.5 W/mK in the X/Y direction

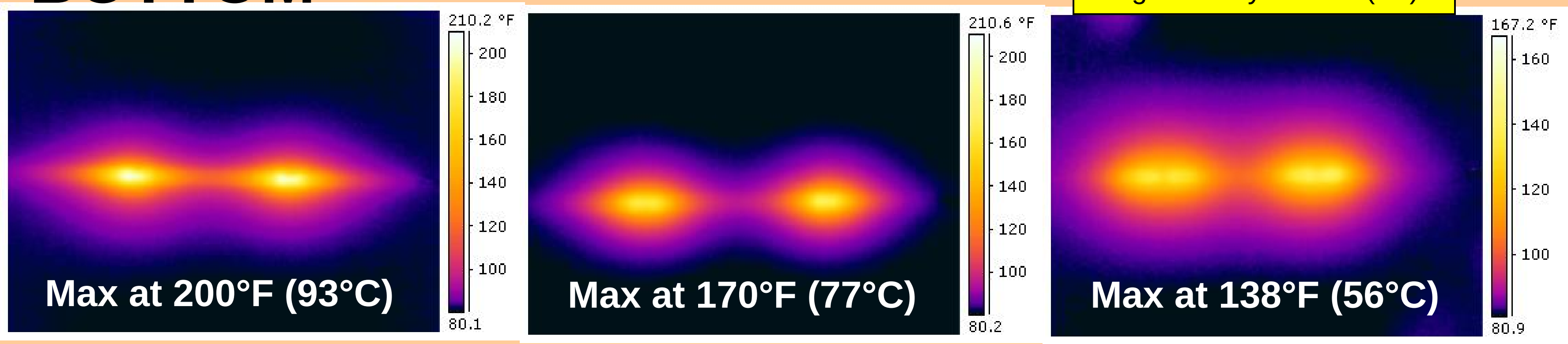
Comparison – 0.3, 1.0 & 2.0 W/mK

TOP



Heat spreading associated with 92ML is related to higher TCxy vs TCz (2X)

BOTTOM



45N **91ML** **92ML**

Conclusions

- Traditional 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 component reliability
  - Improved Solder joint reliability - less work hardening, less thermal expansion from “less heat” and lower CTE properties
  - Improved power handling
  - Complements existing thermal management tools
- TC600 Product has been commercialized (launched). Beta Site Tested.
- TC350 still requires production qualification, but should be feasible based on current results. Beta Sampling expected in November/December 2007

Wish List

- Better understanding of system trade-offs and specific application constraints of thermal management tools in RF applications
- Gain Knowledge of customer acceptance of *"non-traditional dielectric constant"* laminates with higher thermal conductivity
  - "Traditional" is considered 2.55, 3.50, 3.58, 6.15, 10.2
  - Interest in 3.80 at 0.9 W/mK, 6.40 at 1.2 W/mK, etc??
- Customers willing to qualify materials and provide Arlon feedback on material ……. also provide insight with ***"where do we go next?"***