TECHNOLOGY ENABLING INNOVATION

March 2011

Dr. Ron Kirby

Arlon Materials for Electronics

Arlon-MED Presents …

High Frequency Materials for RF Applications in Base Stations

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LTE/4G Technology Trends

- **Higher Data Rate and Throughput**
  - Downlink: 10-100Mbps typical; Uplink: 5-50Mbps typical; Scalable bandwidth: 1.25, 2.5, 5, 10 to 20MHz.
- **Ultra Lower Latency**
  - Enhanced user experience
  - Real-time and interactive applications, such as online gaming and media sharing.
- **Lower Cost per Bit**
  - Increased spectral efficiency and flexibility
  - Added capacity of subscribers per BTS
- **Many carriers and service providers have pledged to deploy or deployed LTE networks.**

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Impacts on Base Stations

- LTE is driving the deployment of new and refurbished base stations, and the market is projected to grow to ~7million deployed BTS by 2014, according to In-Stat.
- In-Stat research also found the following:
  - WCDMA/HSPA/HSPA+ base stations remain the largest revenue segment through 2013.
  - The transition between 2G to 3G, HSPA, and LTE airlinks will also require reconditioning or redeploying existing base stations. Support for multi-mode (GSM/CDMA/WCDMA/HSPA/LTE) airlinks is now requisite.
  - The average selling price for macro base stations will gradually decline.
  - Downward pricing pressures in semiconductors will be offset by increasingly sophisticated software-based QAM, and increasingly more complicated MIMO antenna arrays.

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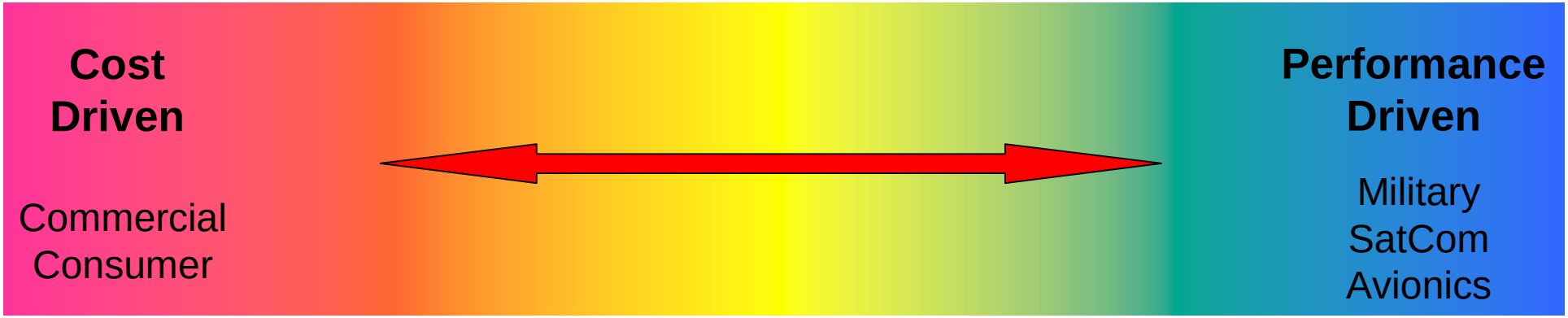
RF Materials - Cost/Performance Space



- Cost Driven
  - Low cost, Low loss materials
    - Commercial PTFE
    - Low cost, low loss Thermosets
    - Low variety of dielectrics & metal cladding
    - Low Test requirements
  - Focus on lower processing costs for PCB fabrication
  - Simplify designs to reduce assembly complexity and costs
- Performance Driven
  - High performance PTFE materials
    - Very low loss
    - Thin dielectrics for multilayer circuits
    - Temperature stability
    - Low thermal expansion
    - High variety of dielectrics & metal cladding
    - High Test requirements

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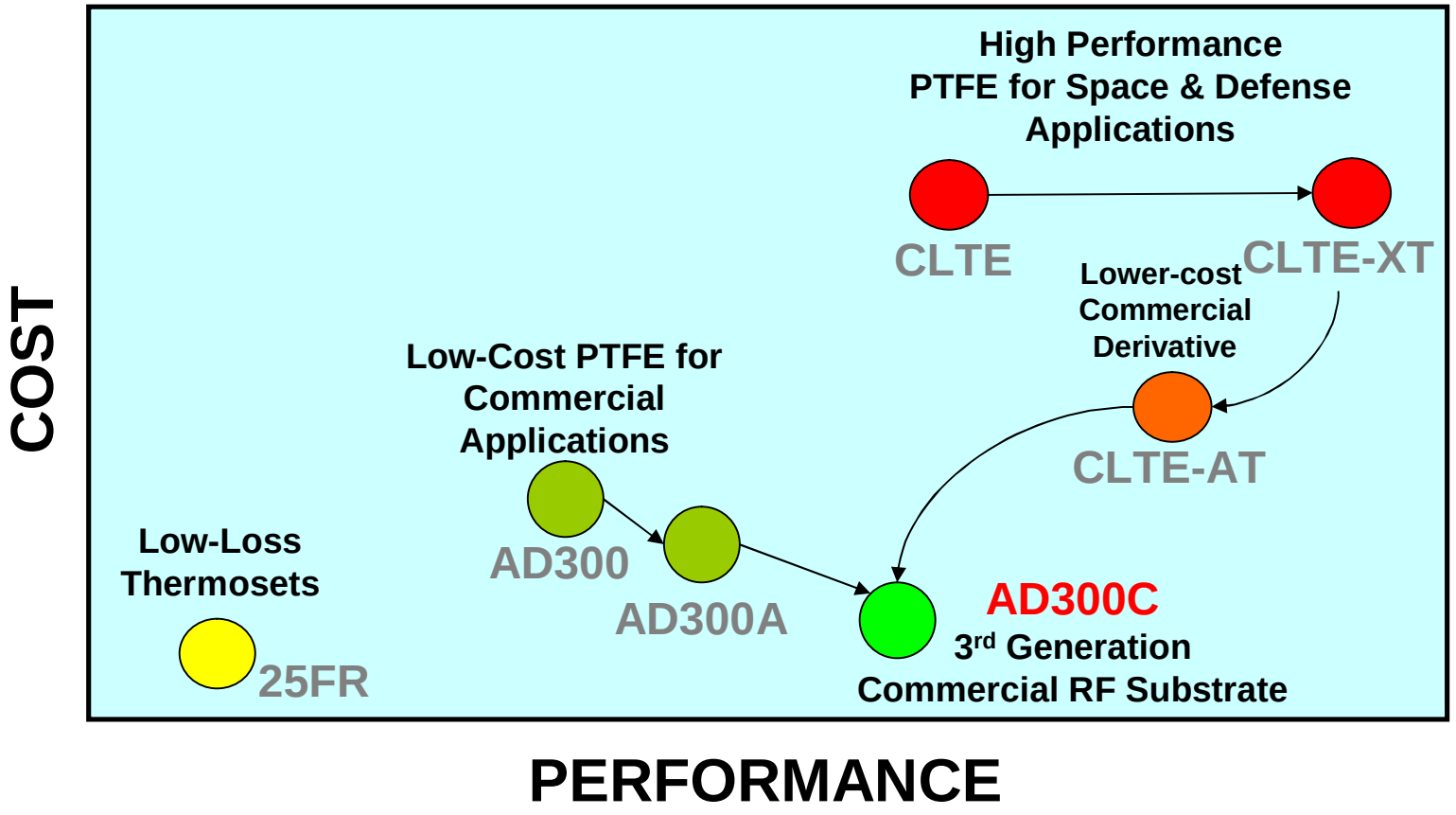
Evolution of Cost/Performance for RF Materials



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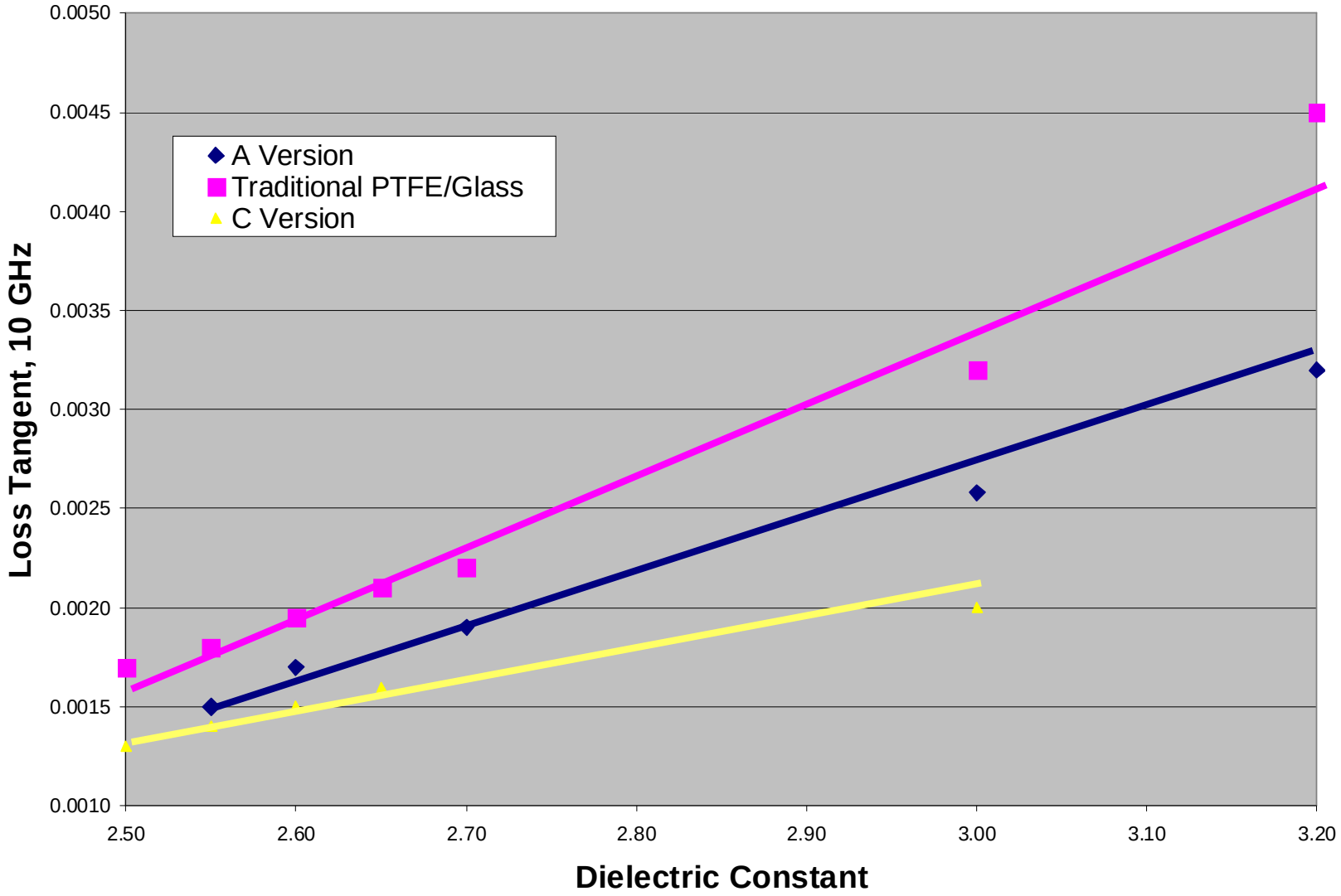
AD-Series Comparison



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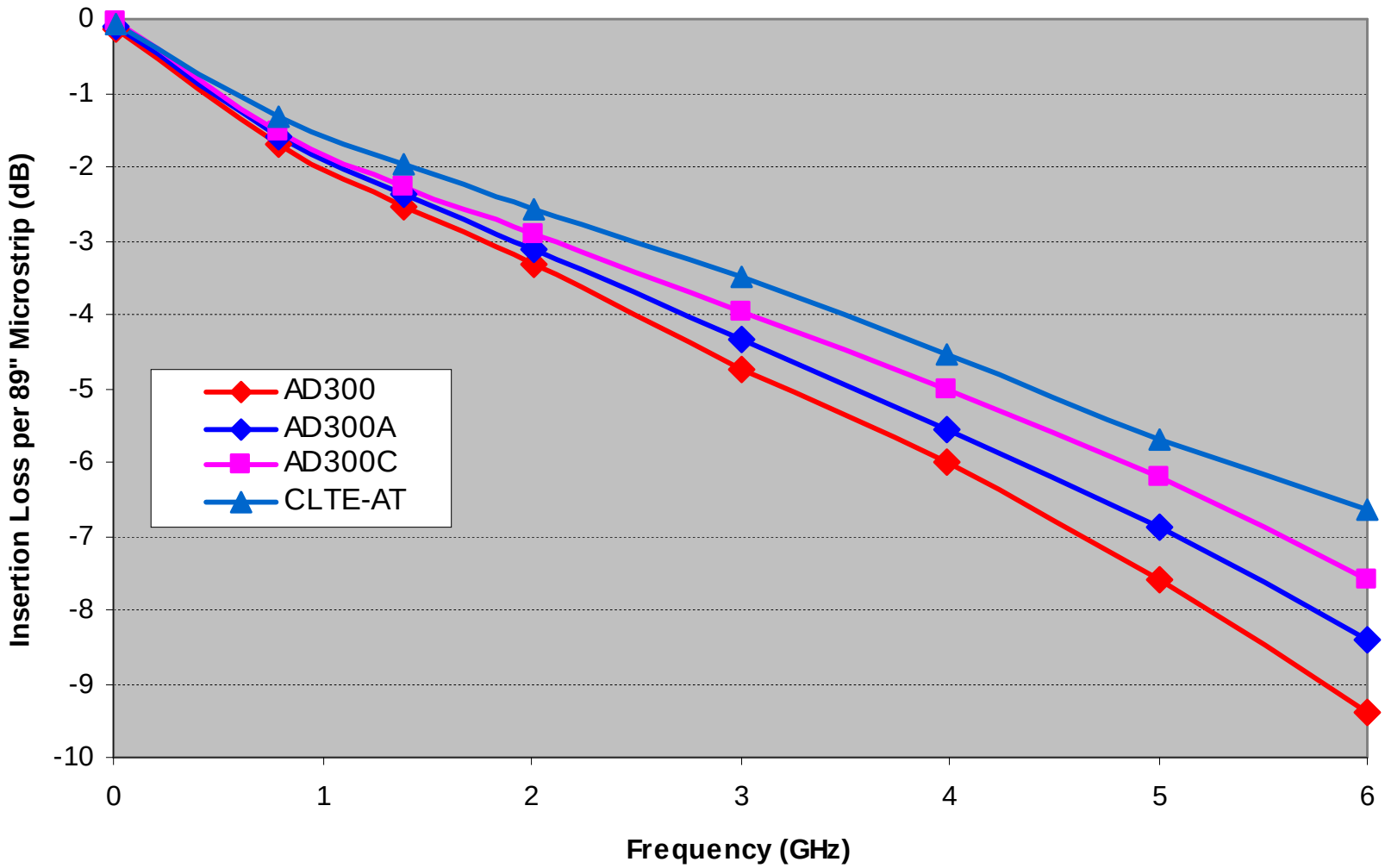
Dk3.0 Insertion Loss Comparison



Arlon Low PIM Series

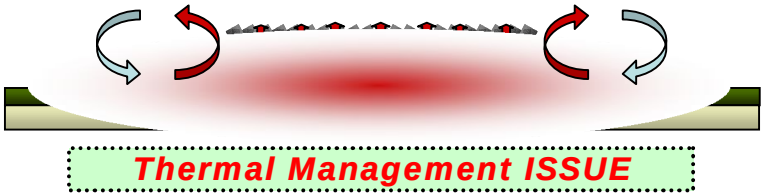
Arlon PIM-Grade Products

Features:
- Designed to Reduce PIM Distortion
- Optimized Copper/Laminate Interface

Benefits:
- Greatly reduces the production of new, unwanted signal frequency components from intermodulation
- Improved Receiver Performance
- Measured PIM values < -155 dBc

Typical Applications:
- A single site with two or more base station transceivers
- High Transmitter signals levels
- High Receiver sensitivity
- Transmitters and receivers sharing a common antenna

Arlon Thermally Conductive Series



Thermal Management Fundamentals:

- Primary Issue is Device Temperature
  - MTBF Halved for Every 10°C Increase in Temperature
  - Heat Generated by Active Devices Causes Temperature to Rise
  - Removing Heat Decreases Temperature

- Three Principal Modes of Heat Transfer
  - Conduction: Direct Flow of Heat from Hot body to Cooler body
  - Convection: Heat Removed by Cooler Liquid or Gas
  - Radiation: Heat removed by radiated energy (Infrared, Microwave)

- The basic equation for conductive heat flow is: **$dQ/dt \sim Tc*(A/Tk)*\Delta T$**, where
  - dQ/dt is the rate of heat flow
  - Tc is the coefficient of heat transfer (W/m-K)
  - A is the surface area between the hot and cool materials
  - Tk is the thickness of the interface material
  - ΔT (delta T) is the temperature difference between the two materials

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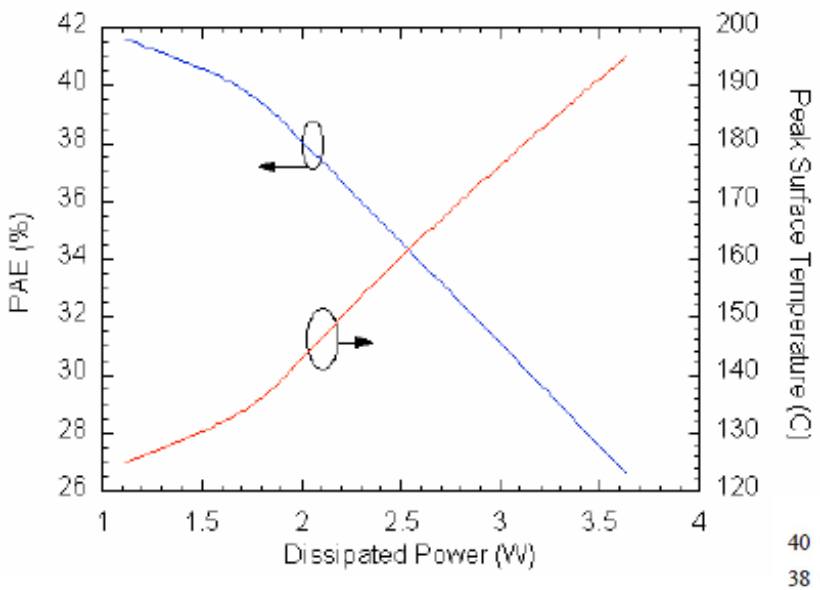
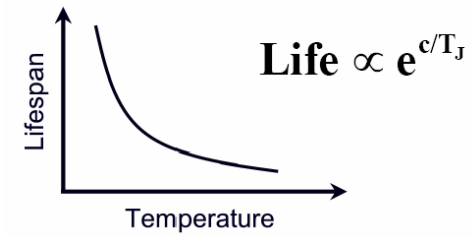
Examples: RF Power Amplifier's Performance vs. Temperature



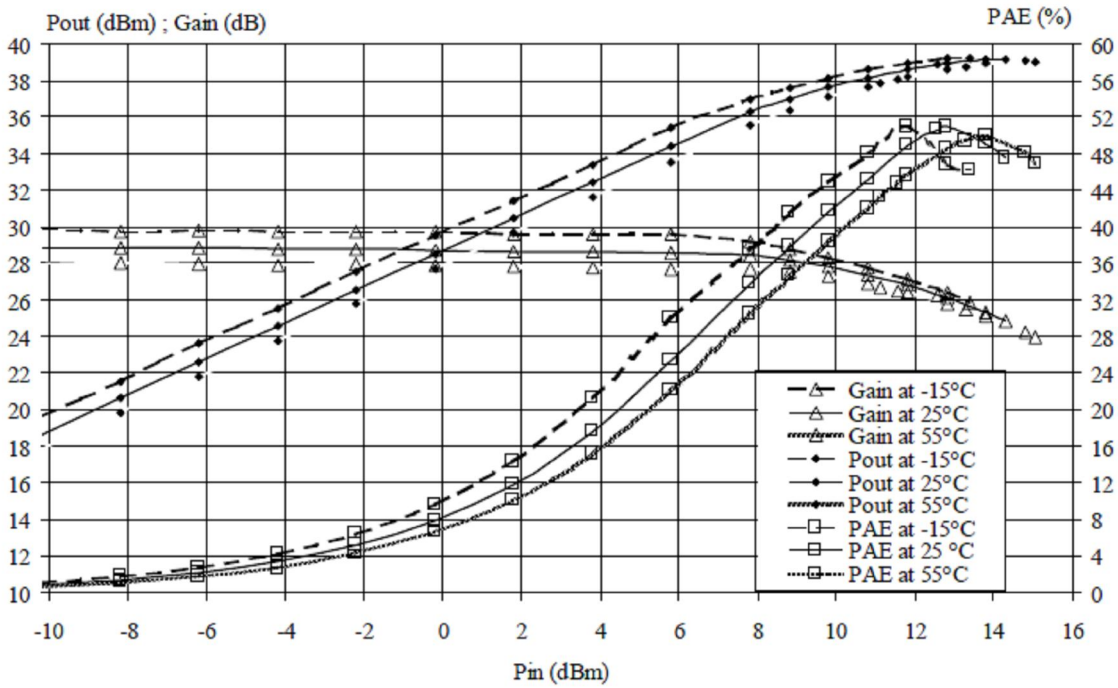
S. Nuttinck, R. Mukhopadhyay, C. Loper, S. Singhal, M. Harris, J. Laskar, "Direct On-Wafer Non-Invasive Thermal Monitoring of AlGaN/GaN Power HFETs Under Microwave Large Signal Conditions."

$$\eta_{PAE} = \frac{P_{RF\_Out} - P_{RF\_In}}{P_{DC}} \times 100\%$$



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

Butel, Y. Adam, T. Cogo, B. Soulard, M. , "High Efficiency Low AM/PM 6W C-band MMIC Power Amplifier for a Space Radar Program."



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TC-Series Competitive Comparison

Key Properties	TC350	TC600	Compared to Classes
Dk (@ 10 GHz)	3.50	6.15	PAR
Df (@ 10 GHz)	**0.0020**	**0.0020**	Match or better
Df (@ 1.8 GHz via Circular Cavity	0.0018	-	Match or better
TCEr (*ppm/°C*)	**-9**	**-75**	**Much better**
Thermal Conductivity (*W/mK*)	**1.0**	**1.1***	**2x-4x Better**
CTEx,y (*ppm/°C*)	7	9	Better
CTEz (*ppm/°C*)	23	35	Better
Copper Peel (*lbs/in*)	7	8	Match or better
Moisture Absorption(%)	0.05	0.02	Match or better

* For TC600, TCz is 1.1W/mK and TCx,y is 1.4 W/mK.

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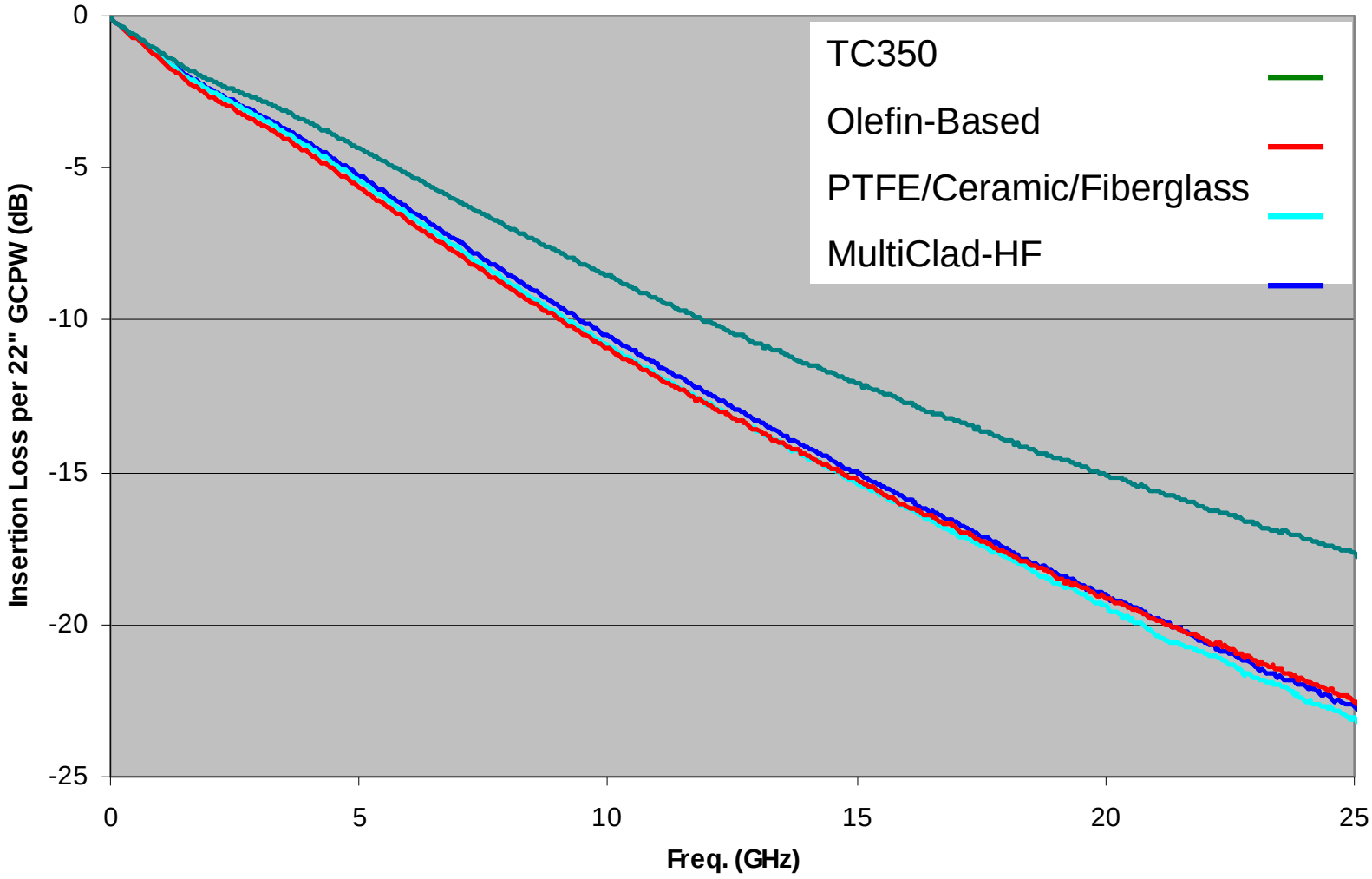
Insertion Loss for Dk3.5 Materials



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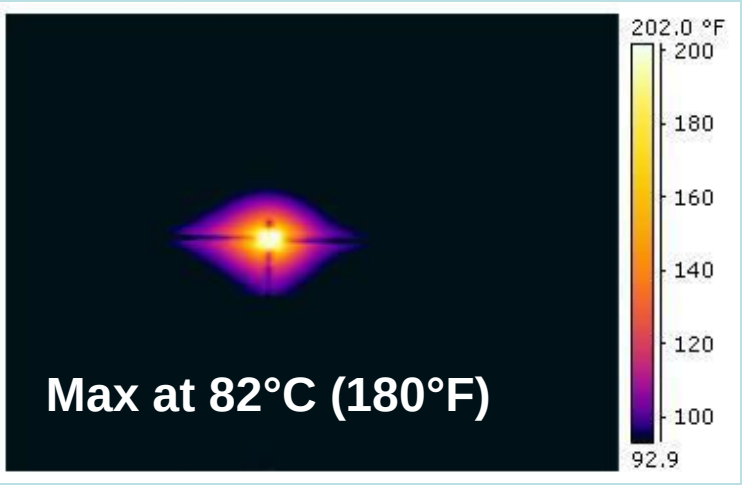
RF Power Field Effect Transistor

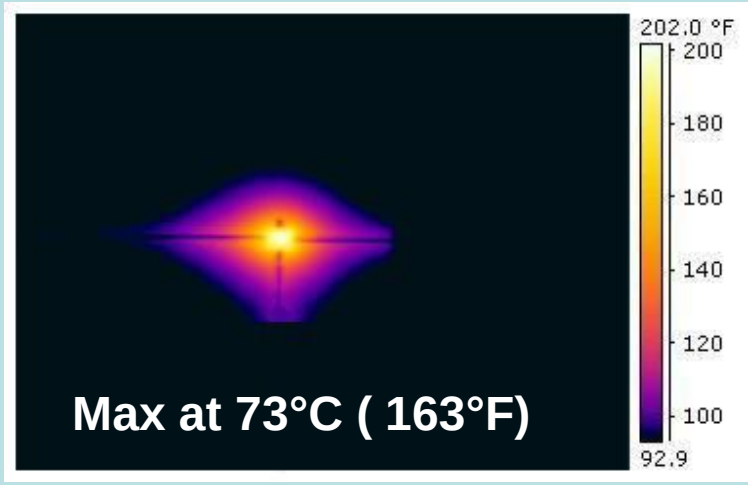
Heat spreading associated with TC600 is related to higher TCxy vs TCz

Alternative (TCz = 0.46)

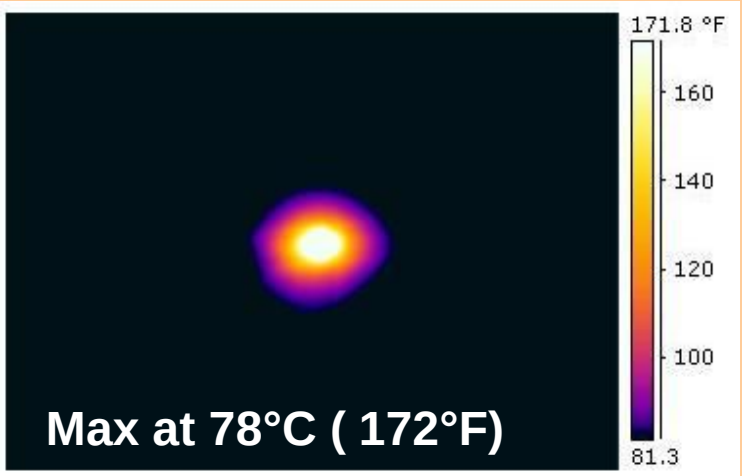
TC600 (TCz = 1.1)

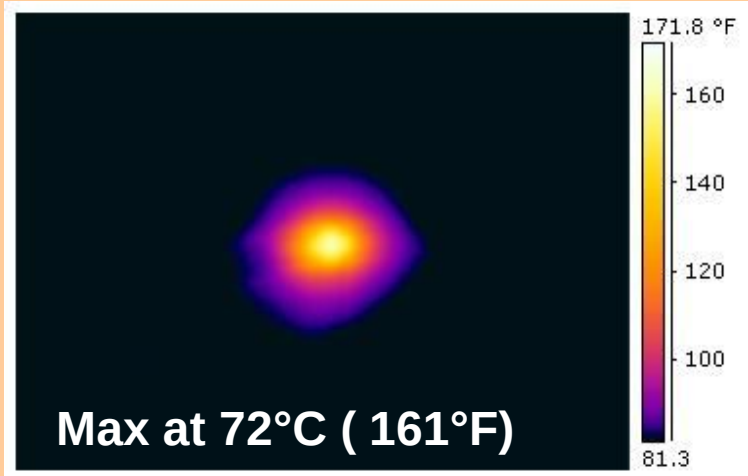
Top





Bottom





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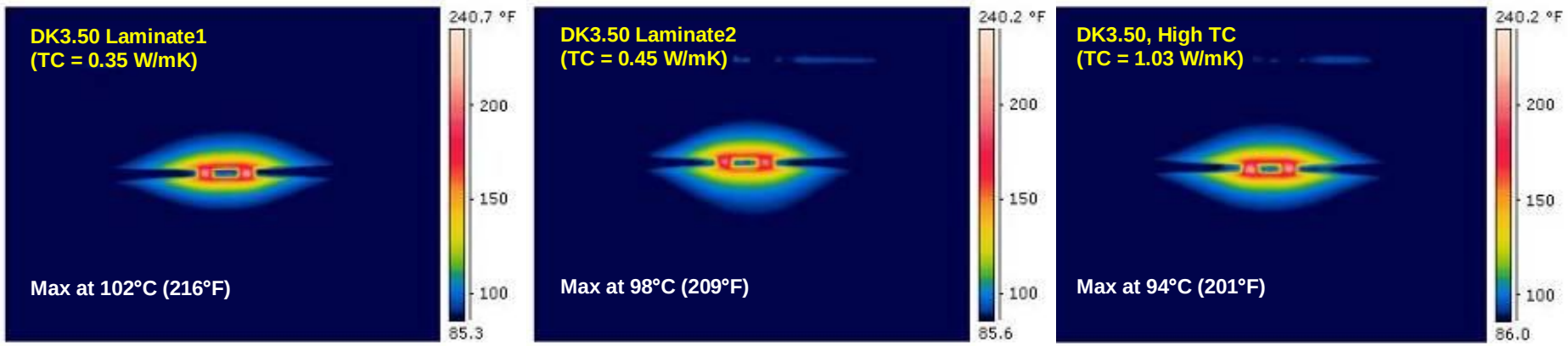
Thermal Testing - Power Resistors



RF Materials	TC (W/m-K)	Area > 30 ° C (86 ° F)
DK3.50 Laminate1	0.35	1.00
DK3.50 Laminate2	0.45	1.34
DK3.50 High TC	**1.03**	**1.42**

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Arlon Thermally Conductive Series

Features:

- "Best in Class" Thermal Conductivity and Dielectric Constant Stability
- Very Low Loss Tangent provides Higher Amplifier or Antenna Efficiency
- Priced Affordably for Commercial Applications
- Easier to drill than traditional commercial based laminates
- High Peel Strength for Reliable Copper Adhesion under thermal stress

Benefits:

- Heat Dissipation and Management
- Improved Processing and Reliability
- Large Panel Sizes for Multiple Circuit Layout for lowered Processing Costs

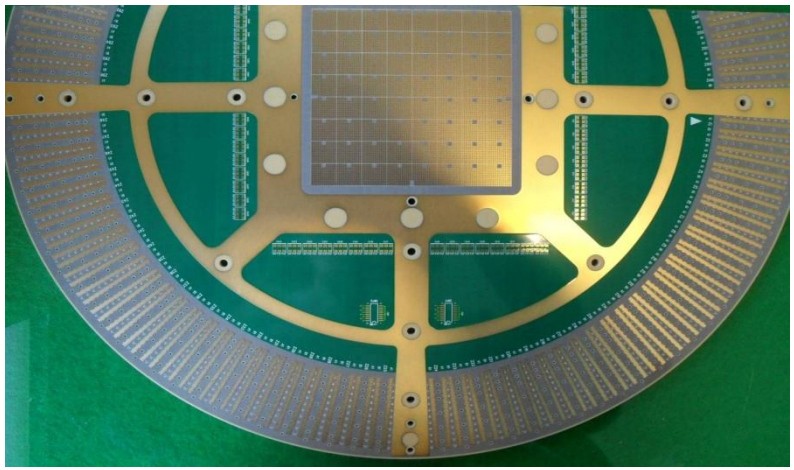
Typical Applications:

- Power Amplifiers, Filters and Couplers
- Tower Mounted Amplifiers (TMA) and
- Tower Mounted Boosters (TMB)
- Thermally Cycled Antennas sensitive to dielectric drift
- Microwave Combiner and Power Dividers

What is MultiClad HF

MultiClad HF is ARLON's new halogen-free low-loss system and represents the next generation low-loss multilayerable thermoset laminate and prepreg system for microwave and high-frequency printed circuit boards.

This new technology combines a ceramic-filled low-loss, high reliability thermoset resin system with bromine-free flame retardant system to create a material that is unmatched in terms of electrical performance, mechanical stability, thermal reliability and cost.



SGS

Test Report No. : CE/2010/32613 Date : 2010/03/12 Page : 3 of 7

ARLON ELECTRONIC MATERIALS, INC.
9433 HYSSOP DRIVE, RANCHO CUCAMONGA, CA 91730

Test Item (s):	Unit	Method	MDL	Result No.1
Halogen				
Halogen-Fluorine (F) (CAS No.: 014762-94-8)	mg/kg	With reference to BS EN 14582:2007. Analysis was performed by IC.	50	108
Halogen-Chlorine (Cl) (CAS No.: 022537-15-1)			50	n.d.
Halogen-Bromine (Br) (CAS No.: 010097-32-2)			50	n.d.
Halogen-Iodine (I) (CAS No.: 014362-44-8)			50	n.d.

Note : 1. mg/kg = ppm; 0.1wt% = 1000ppm
2. n.d. = Not Detected
3. MDL = Method Detection Limit
4. " - " = Not Regulated

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MultiClad-HF Highlights

- Thermal properties rival industry-leading Polyimide materials for T288/T300 and Z-Axis Expansion
  - High Glass Transition temperature (190-200ºC)
  - Z-axis Thermal Expansion almost identical to copper under Tg
- Electrical performance rivals low-loss thermosets
  - Design values for competitive product reported at ~3.7
  - Significantly better loss than standard high speed FR-4
  - High Peel strength enables use of Very Low Profile or Reverse Treat copper
- Excellent prepreg handling: not brittle / tacky (Fabricators)
- Flow values are close to standard thermoset products; supports high layer count PCB designs
- Expect price competitive with high Tg FR-4 & low-loss thermosets
- Uniquely halogen-free!

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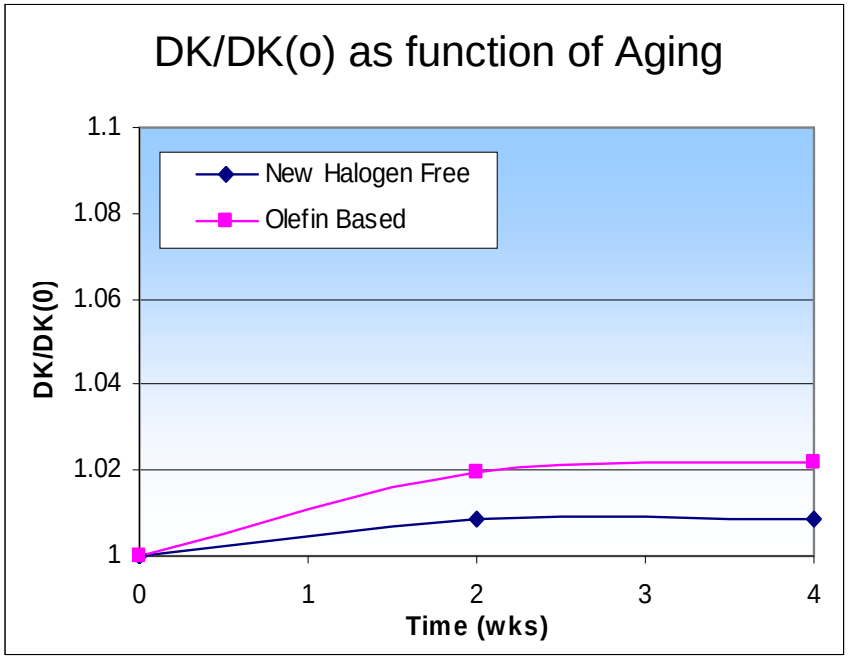
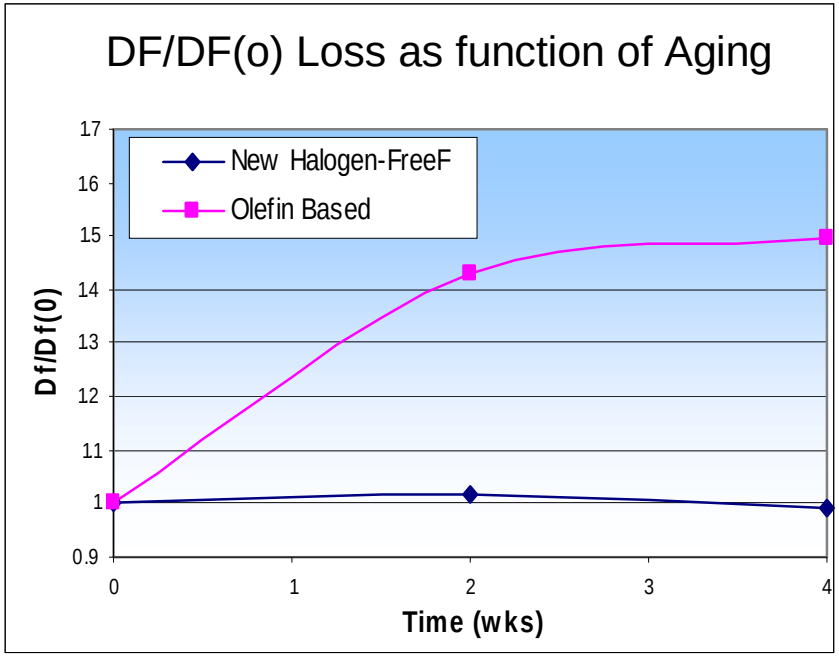
Dielectric Performance

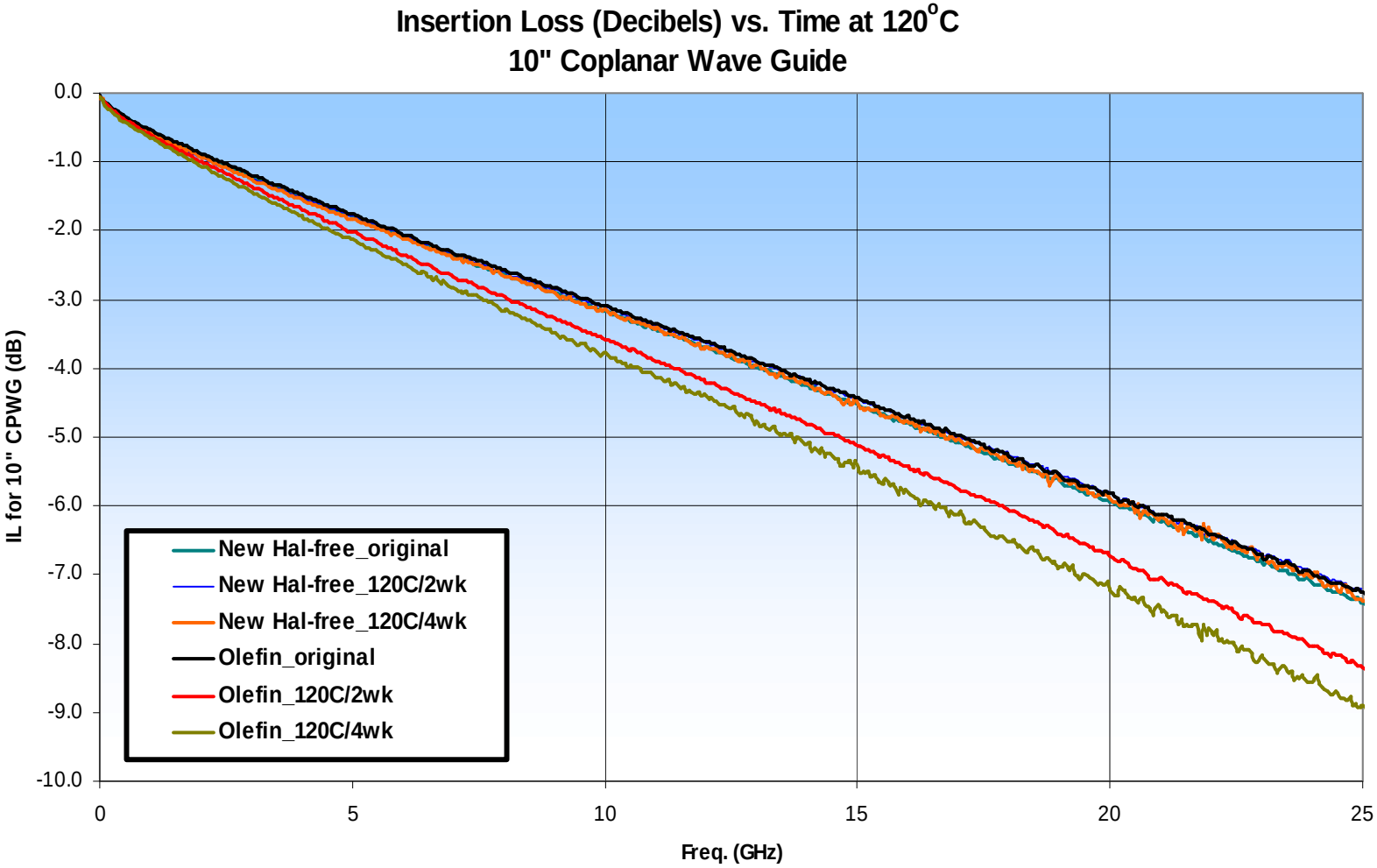
Indexed Dielectric Constant and Dissipation Factor Results

MultiClad HF vs, Competitive Olefin Material





The Effect of Oxidation on Signal Integrity



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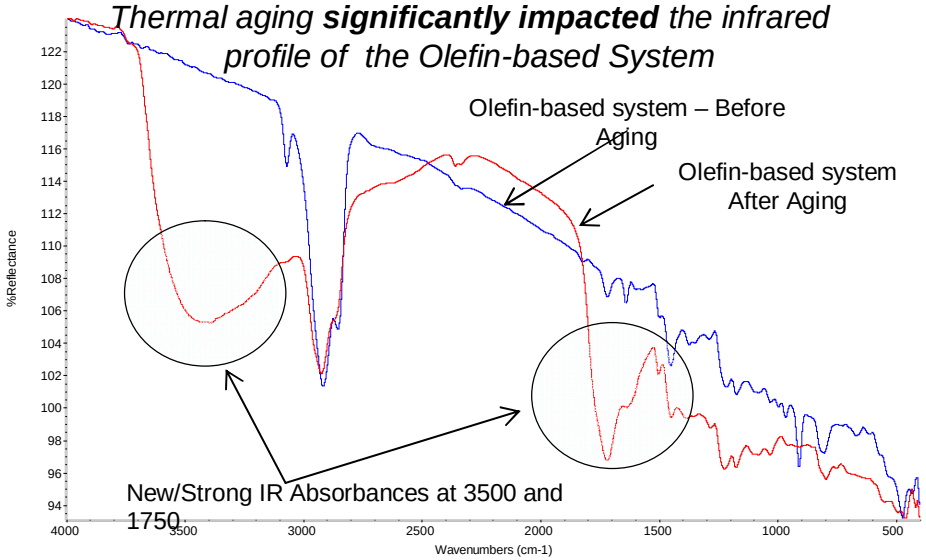
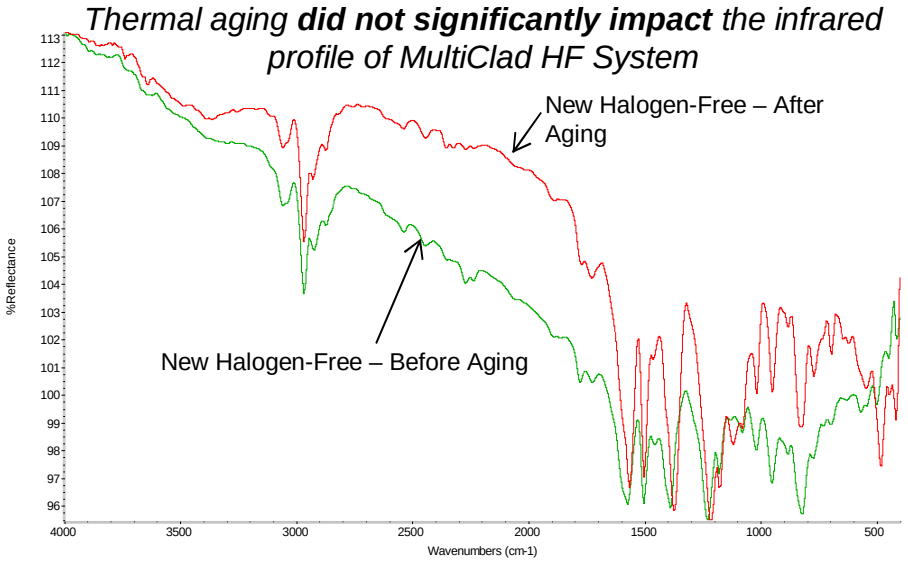
Reliability Study – Thermal Oxidation

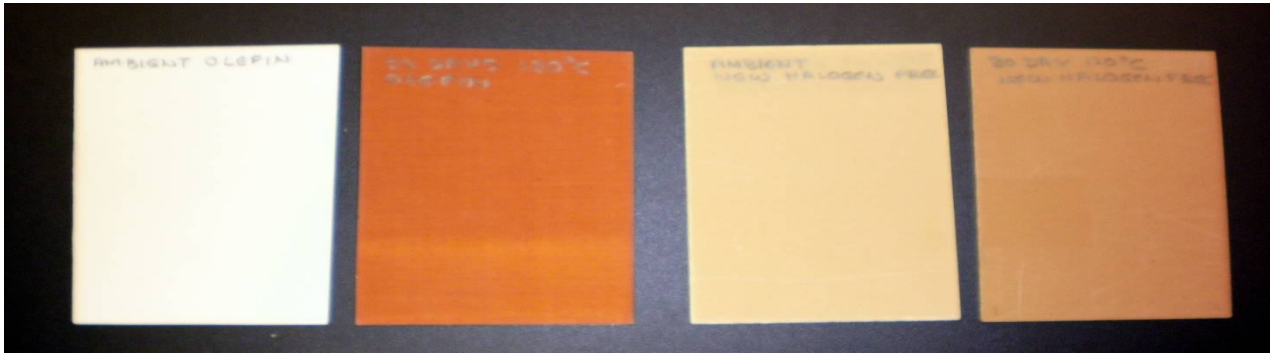
FTIR of samples before and after thermal oxidation or aging.

*Thermal aging **significantly impacted** the infrared profile of the Olefin-based System*



*Thermal aging **did not significantly impact** the infrared profile of MultiClad HF System*





Olefin Based Material

MultiClad HF

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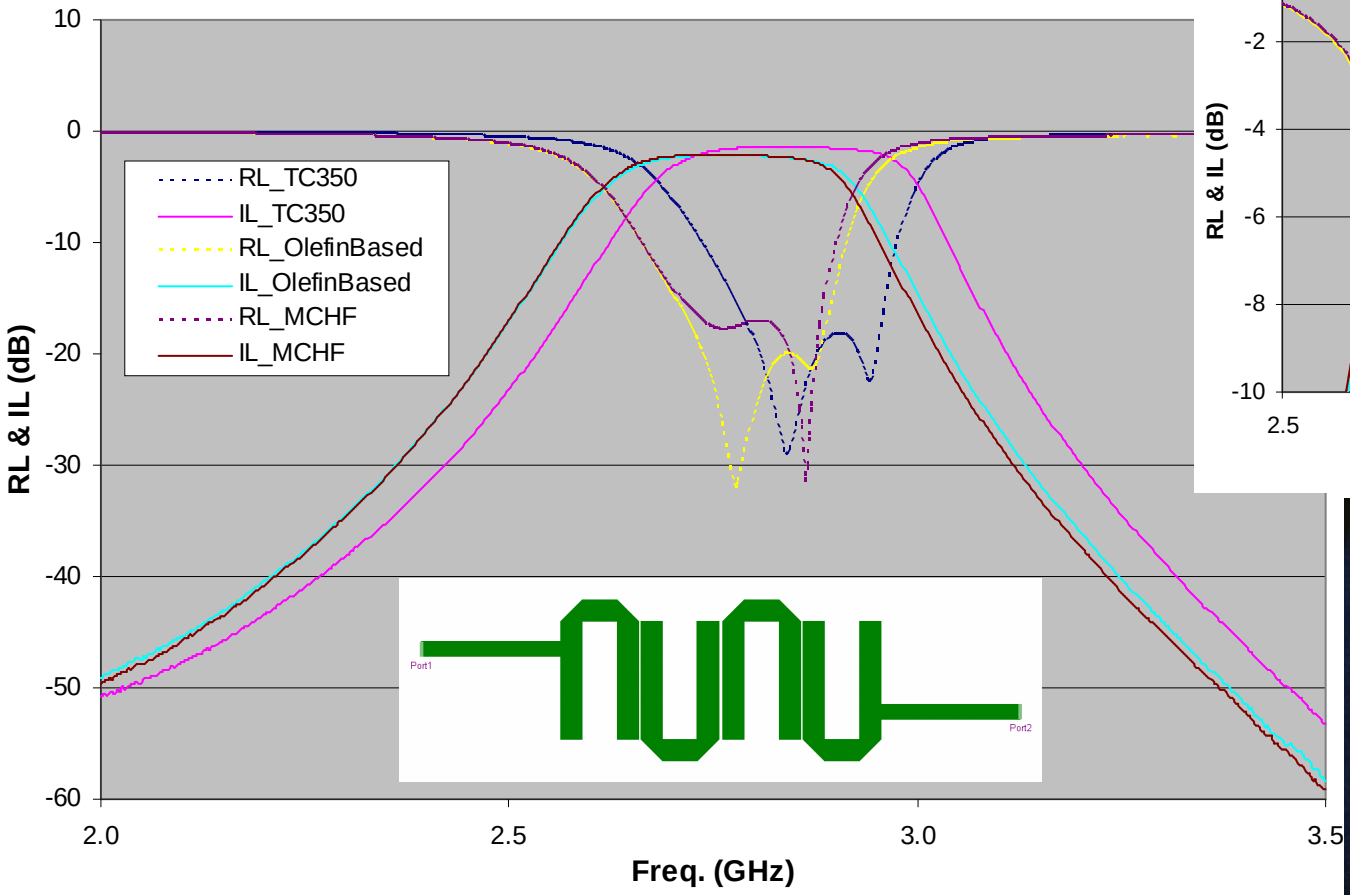
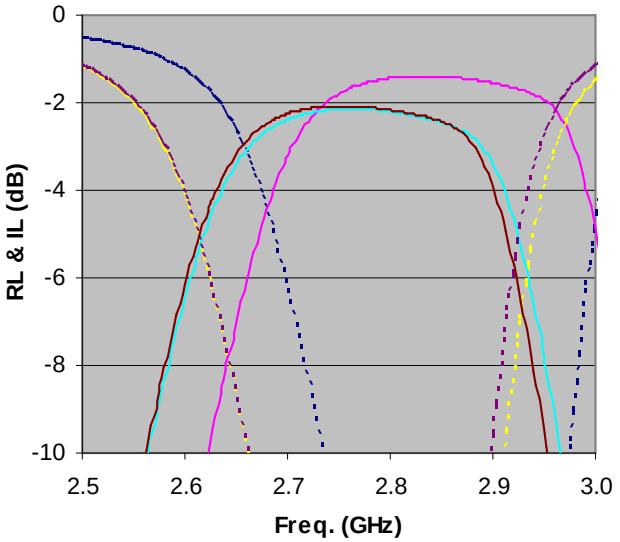
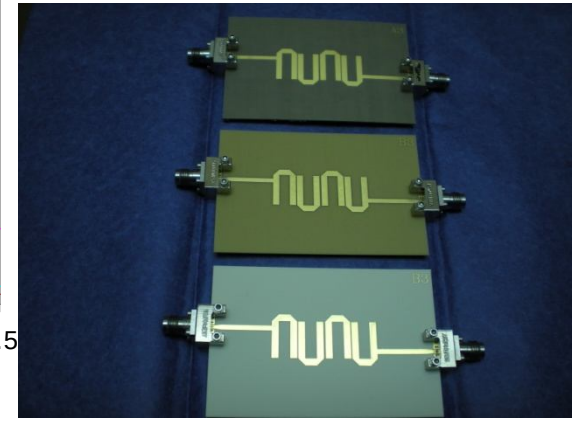
Hairpin Filters – Broadband Design







	Center Freq., GHz	3dB BW, MHz	IL, dB	BW, %
TC350	2.8381	315.06	-1.40	11.10
OlefinBased	2.7723	308.31	-2.17	11.12
MultiClad-HF	2.7642	299.41	-2.06	10.83

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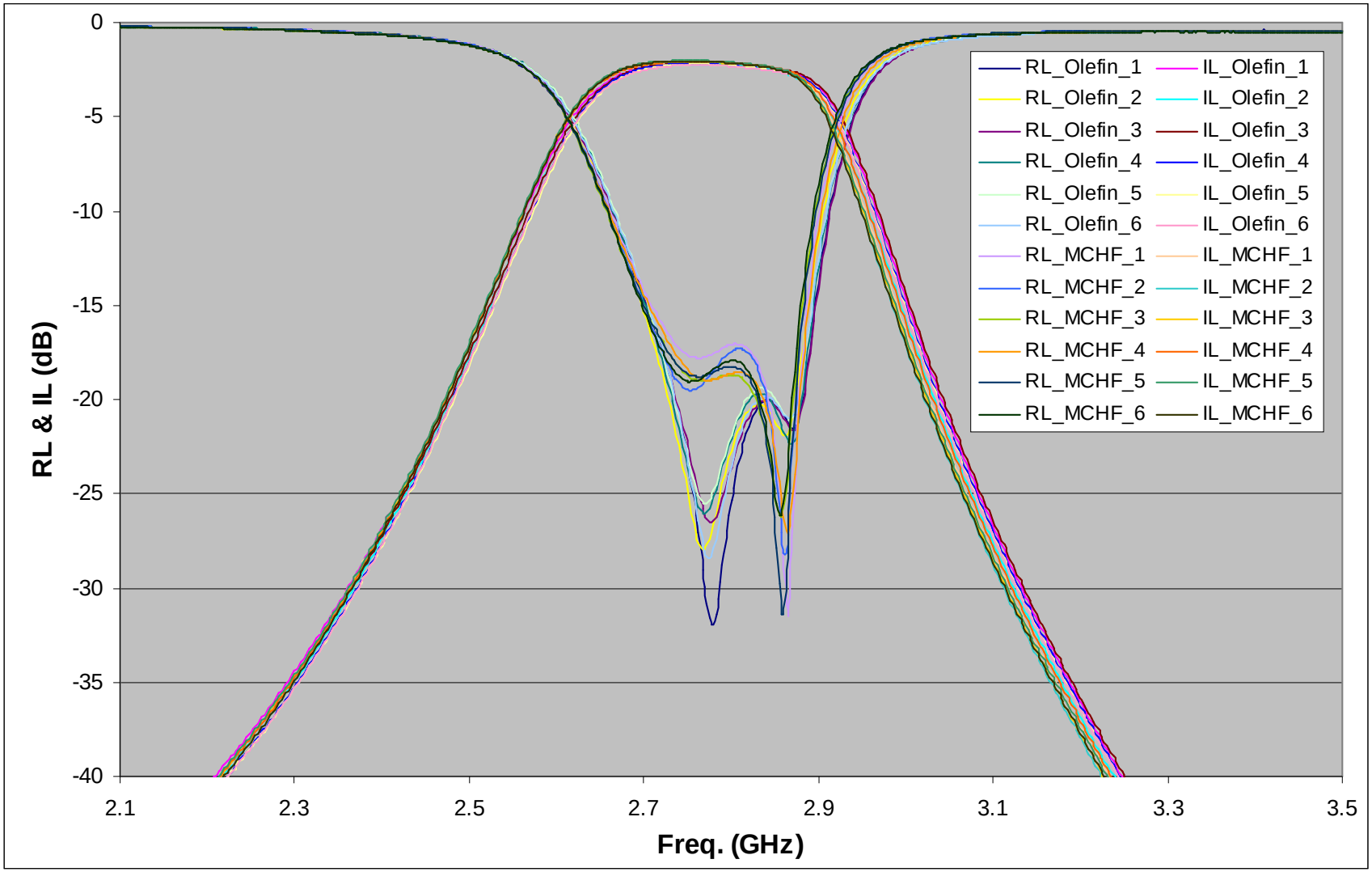
MultiClad-HF - Easy Re-design



* Filters with the same artwork on 30mil boards.

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Conclusion

- With significant improvements in cost/performance over traditional PTFE/Fiberglass based RF materials, Arlon AD-C series are the third generation of commercial laminate materials for today's telecommunication infrastructure.
- Thermally conductive TC-series provide a design option in addition to *"traditional"* thermal management tools to improve RF system reliability and performance, and are critical for tower-top mounted electronics and high power RF PA applications.
- Halogen-free MultiClad-HF represents the next generation low loss, multilayerable thermoset laminate and prepreg system for RF and high data-rate applications. It is environmentally friendly and has unmatched properties in terms of electrical performance, mechanical stability, thermal reliability and cost.

THANK YOU!

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Advanced Materials for the Designs of Tomorrow

www.arlon-med.com