THERMAL DEVELOPMENT OF A COTS CAMERA FOR EXPLORATION UPPER STAGE (EUS)

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Outline

- EUS Camera System Overview
- Thermal Challenges
- COTS Approach
- Thermal Mitigation
- Test Based Modeling
- Thermal Analysis
- Conclusions
- Future Work
- References

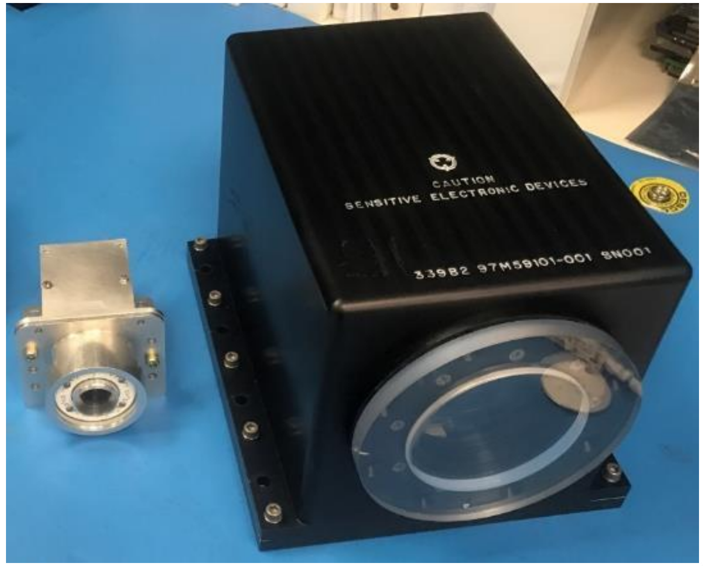
EUS Camera System Design

- Exploration Upper Stage (EUS) Flight Imagery Launch Monitoring Real-time System (EFILMRS)
  - Objective: convert the FILMRS lighted camera for extended use in space while reducing size, volume, and power requirements
- Required complete redesign of system
  - Reduce mass, power and volume
  - Operation in extreme temperatures and vacuum
  - Exposure to Van Allen belt radiation with non-rad-hardened hardware
  - High vibrational loads

Thermal Challenges

- Operation in vacuum environment for an eight hour duration
  – Commercial Off The Shelf (COTS) components typical under perform in space thermal environments (as compared to built for space components)
  – Self heating in cold environments limited due to low camera power
- Thermal Design for three different mounting locations
  – External in a fairing enclosure with limited environmental exposure
  – Equipment shelf with view of engine plume
  – Payload Adapter (PLA) with exposure to orbital environments

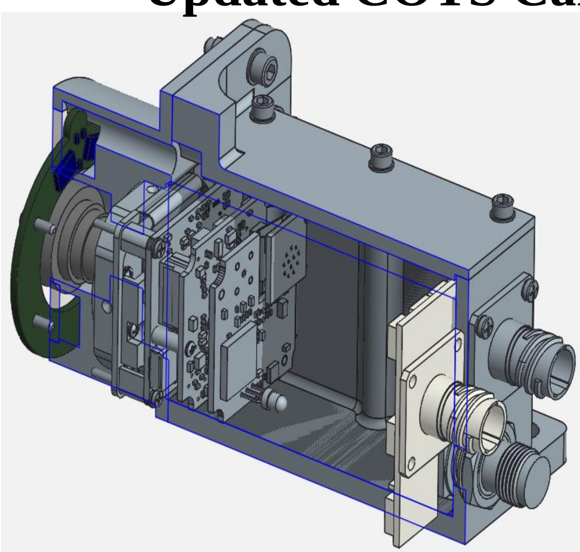
Camera Re-Design

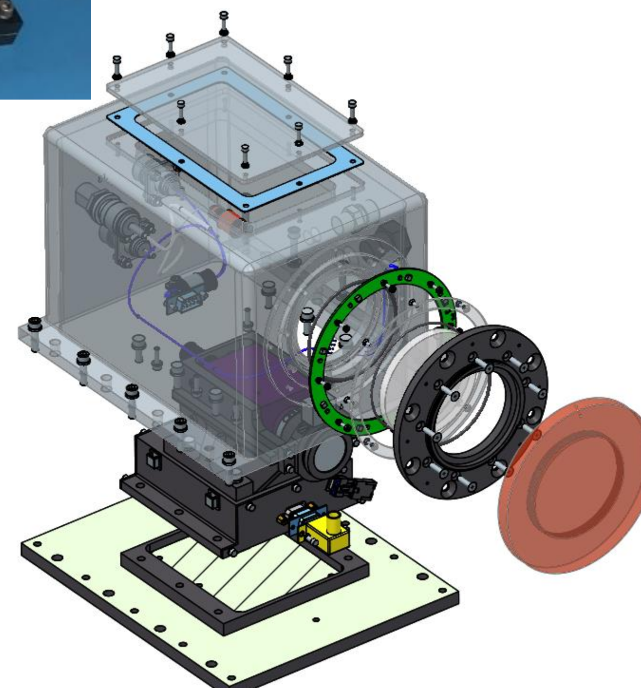


EFILMRS Lighted Camera Assembly (ELCA) Design
- Lighter (~1.5lb)
- Smaller (4.9”x3.3”x2.8”)
- Less Power (10 watts)

FILMRS Lighted Camera Design
- Heavier (13.3lb)
- Larger (9”x7.5”x6.8”)
- More Power (25 watts)

Updated COTS Camera and Lens





COTS Specific Approach

- Use of COTS hardware reduces development time and cost
- Hardware safety design is to “do no harm” to vehicle hardware in the event of a camera failure
  - Cameras are not required to function after a failure
  - Allows more than the typical risk for space flight hardware
- Instead of designing for the environment, the limits of the hardware are defined by testing
  - Typically COTS cannot withstand the temperature extremes of hardware built for space applications
- Determine the thermal design margin with the goal of providing data for risk evaluation by management

Thermal Design Approach

- Passive thermal design used as much as possible to save weight
  - Provide adequate conduction path between the COTS camera and in-house built chassis
  - Provide optical coatings to mitigate extremes
  - Added heaters for cold extremes
- Thermal development testing used to define component limits
  - Define steady state environment limit
  - Provides thermal balance data for model development
- Transient thermal models required
  - Evaluate mitigations for differences between hardware capability and integration environments
  - Determine margin for risk evaluation

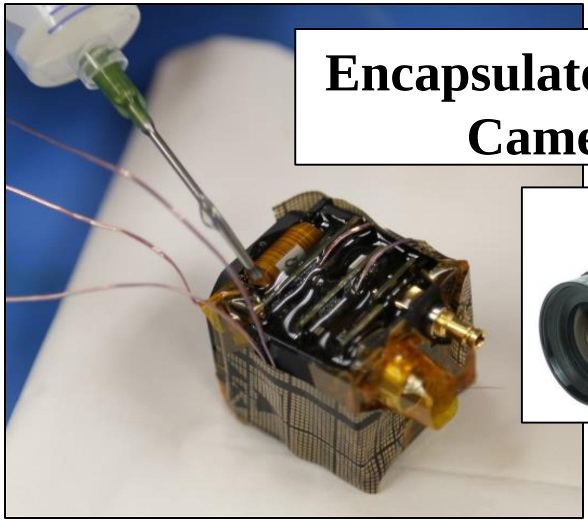
Thermal Mitigations

- Provide adequate conduction path between the COTS camera and in-house built chassis
  - Encapsulation material added to camera chassis
  - Aluminum chassis
  - Mounting location includes filler material: eGraph Hitherm HT-1220
- Provide optical coatings to mitigate extremes
  - Black anodized exterior
  - Sliverized tape [2] for PLA cameras
- Added heaters for cold extremes
  - PLA cameras
  - Isolation of camera from mounting surface: G-10 fiberglass laminate

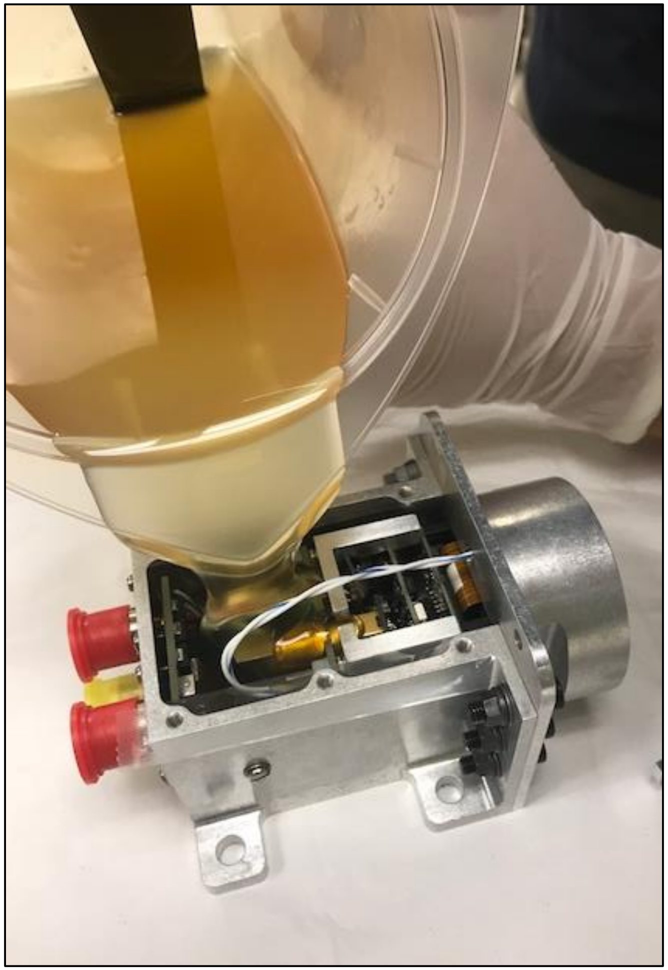
Vacuum Operation Mitigation

<u>Conathane EN-11 [1] Encapsulation added to camera</u>

- History:
  - Has a history of use on NASA probe projects
- Thermal Performance:
  - Improved conduction interface between the COTS camera and in house built chassis with encapsulation material
  - Conductivity = 0.2 W/m/$^\circ$ C
- Structural Performance:
  - Mitigates high-g environments
  - Successfully tested



Encapsulated COTS Camera

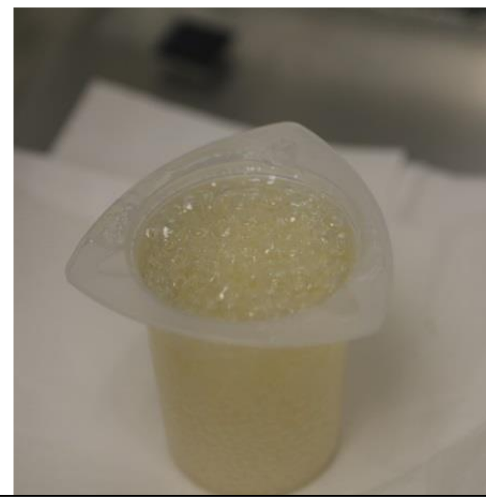


Encapsulation Process for EFILMRS Camera

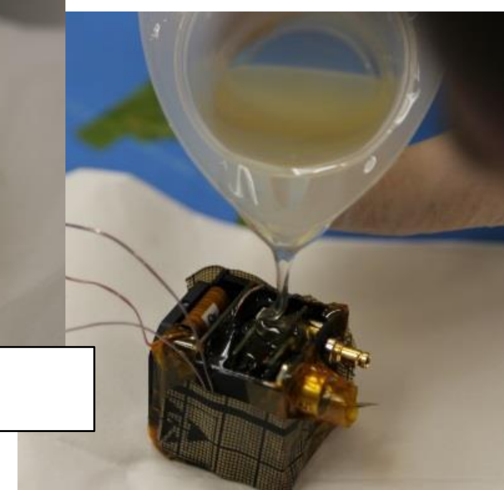
EN-11 Encapsulation Process

- Mix parts A & B
  - Shown being mixed by Jarret Bone, ECCU Designer
- Vacuum degas
- Poor into sealed camera housing
- Oven bake out at 60ºC for 24 hours

Mixing EN-11 epoxy



Vacuum Degas



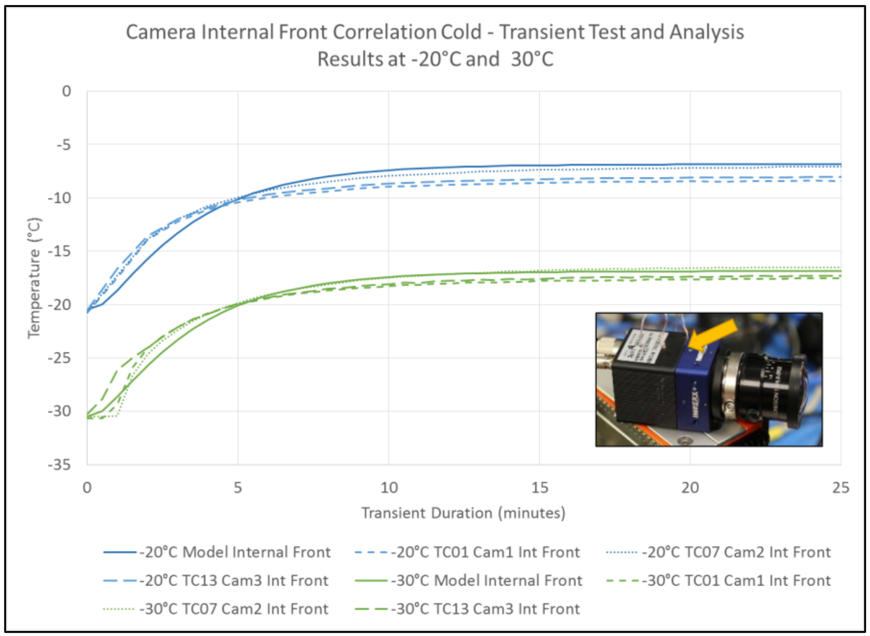
Pour Encapsulate into Camera

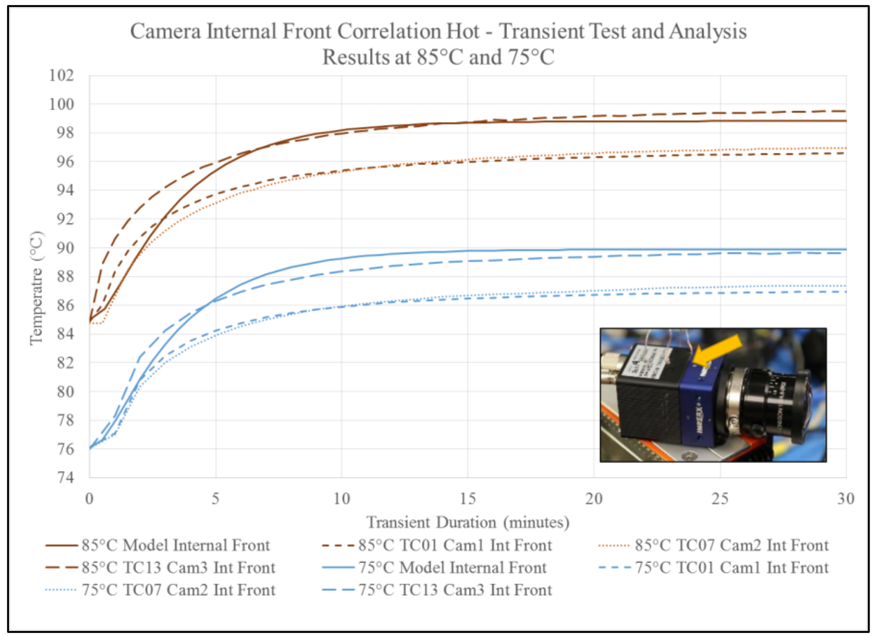
EDU Test Program

- Testing is used to define component limits for specification definition
  - Early development testing of COTS components
  - Design will be qualified to the limits of the hardware
- Early development testing in thermal atmospheric chamber
  - COTS camera encapsulated
  - Vacuum testing showed camera operates in vacuum with encapsulation
  - Initiated acceptance testing of COTS camera on receipt from vendor and after encapsulation
- EDU camera testing to simulate environment extremes in fall 2019
  - Thermal chamber testing for all cases prior to vacuum testing
  - Test cases defined to characterize operational extremes and heater response
  - Test included environments extremes for orbital exposure

COTS Camera Model Correlation

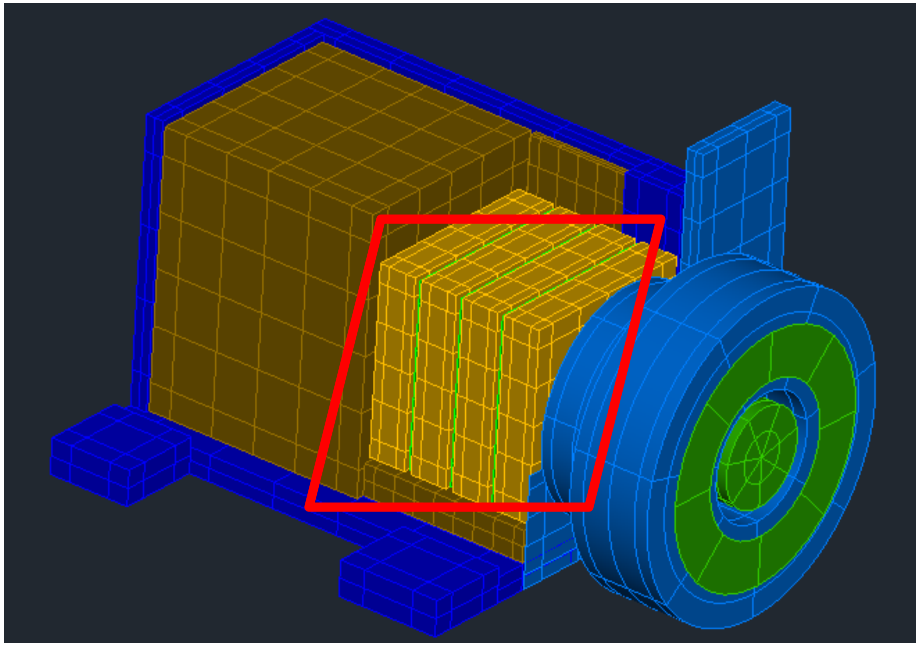
- Encapsulation mimics vacuum operation in atmospheric chamber
  - COTS components in ELCA model are cards and encapsulation only
- Correlated COTS Camera model to thermal chamber testing January 2018 for processing three cameras at 85ºC, 75ºC, -20ºC, and -30ºC



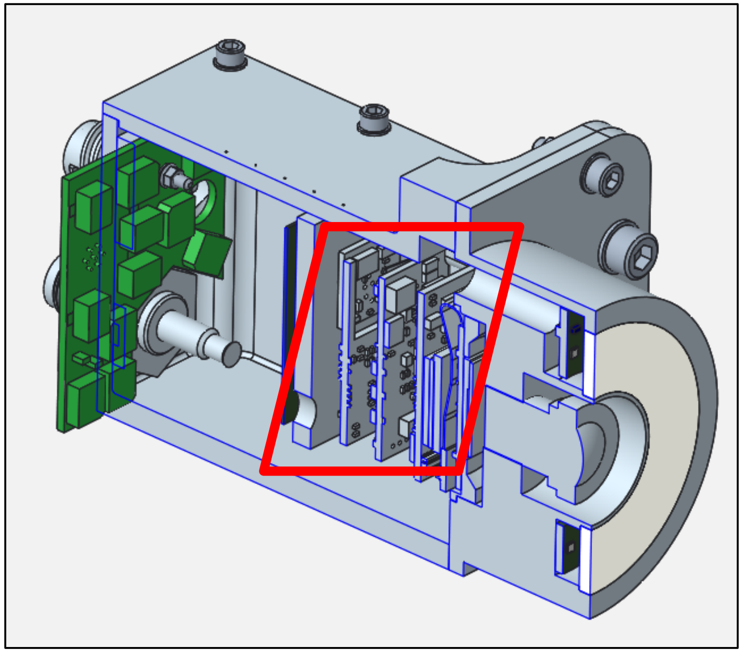


Initial Camera Model Development

- Used camera internals from correlated COTS camera model as a basis for transient thermal model development
- Integrated current CAD design into ELCA model for mass and size
- Assumed continuous operation of camera with lights either on or off continuously



Cut Away Thermal Desktop Model

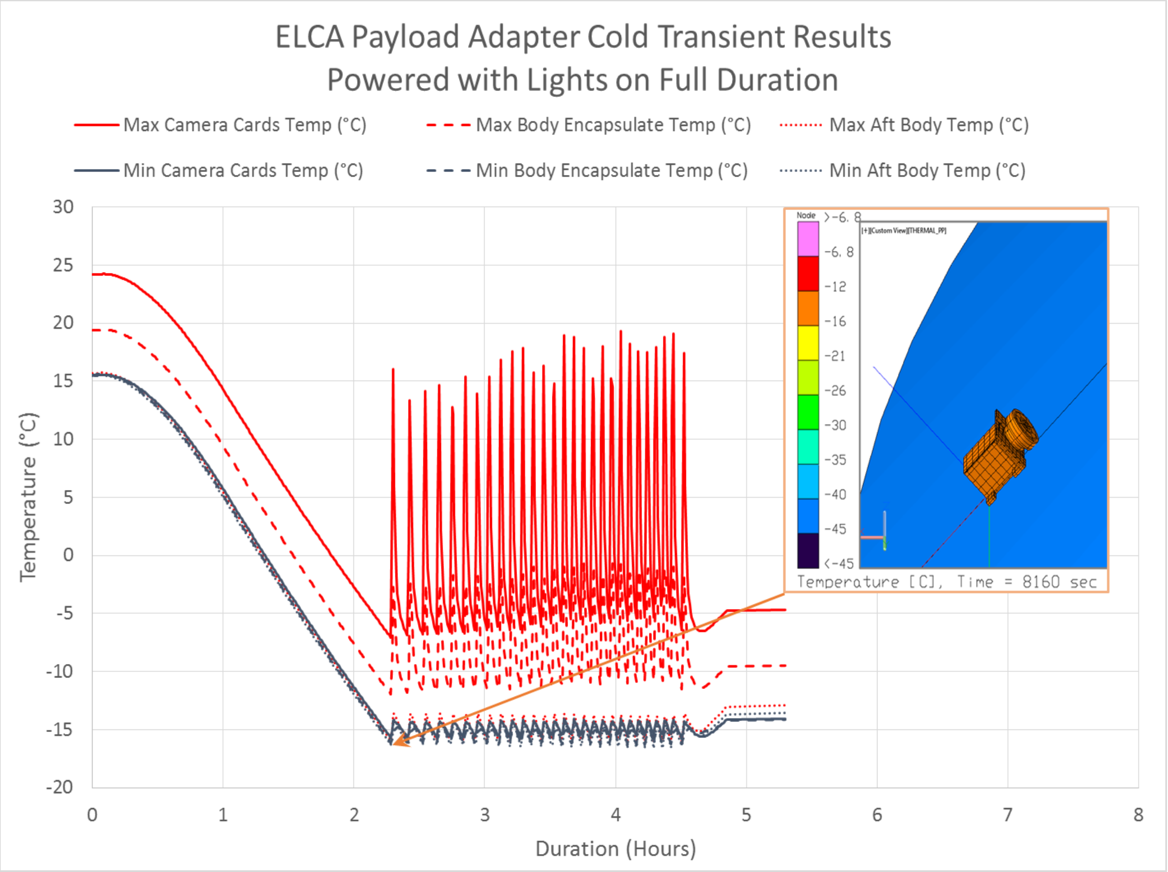


Cut Away CAD Model

Orbital Environment Mitigations

Thermal Design Concept

- Cold environment heaters
  - Power limited to 28W
  - Designed for low dead band
  - Redundant heater runaway prevention
  - Isolation for mounting interface (0.25 inch, G10)
- Hot environment passive control
  - External silver coated FEP tape [2] used minimize solar loads



Conclusions

- Thermal design with COTS requires concurrent thermal development testing to characterize performance and define operational limits
- Encapsulation benefits thermal heat transfer in vacuum
- Thermal design of enclosure can improve thermal performance significantly
  - Isolation from environment
  - External coatings
  - Build in conductive paths
  - Add heater as needed

Future Development and Application

Forward work

- Initial heater sizing transient thermal model evaluation in progress
  - PLA with exposure to orbital environments later in mission
- Environmental Integrated EDU Vacuum testing in Fall 2019
  - Thermal balance testing for thermal transient model development
  - Post test transient model correlation and flight environment analysis

Other Application

- Camera included in Low-Earth Orbital Flight Test on Inflatable Decelerator (LOFTID)
  - Demonstration of advance inflatable aeroshell
  - Camera used to provide visual spectrum data for comparison to IR data collected

References

1) Cytec Industries, Conathane EN-11, www.cytec.com/conap
2) Sheldahl, Red Book, Rev C, Second Surface Silver Coated FEP Tape with Acrylic 3M™ 966 Adhesive, page 62, www.sheldahl.com
3) T. Panczak, S. Ring, M. Welch, D. Johnson, B. Cullimore, D. Bell. *C & R Technologies (R) Thermal Desktop (R) User's Manual, A CAD Based System for Thermal Analysis and Design, Version 6.0.*