INTEGRATED VEHICLE
HEALTH MANAGEMENT

Lightning Damage Diagnosis Research for Composite Aircraft

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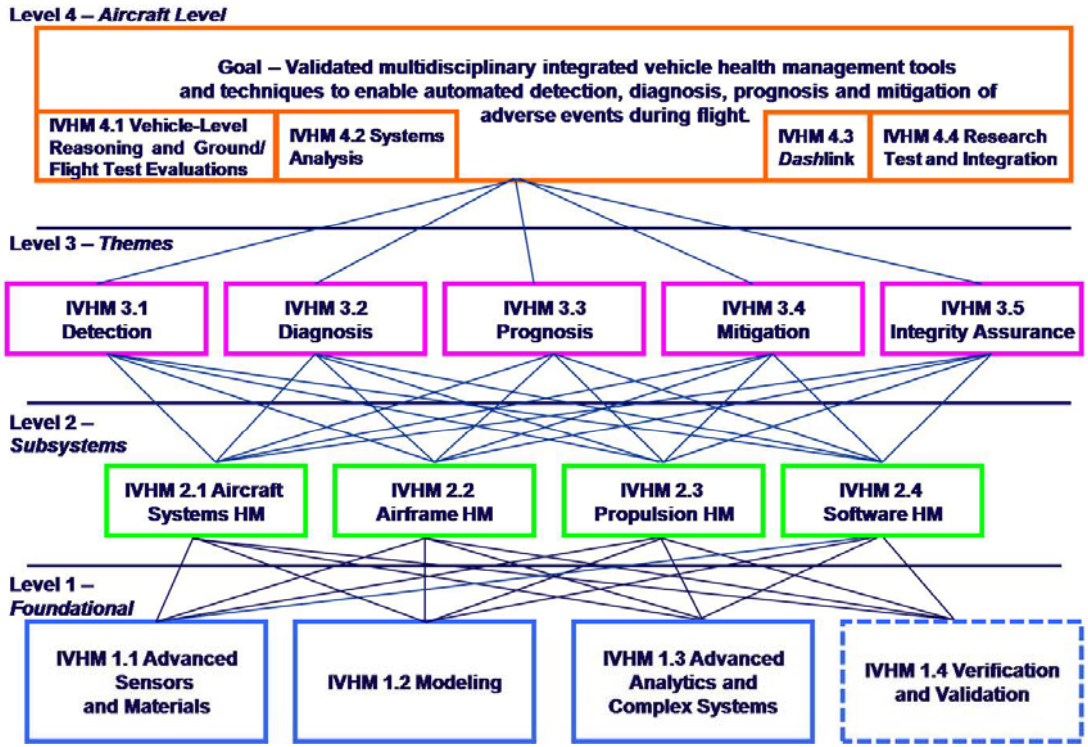
Outline

- Problem Statement
- Background
- IVHM milestones(s) being addressed
- Approach
- Results
- Conclusions
- Future Plans

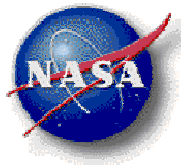


Problem Statement

- Composite aircraft are more susceptible to lightning damage
  - Aircraft are struck on average once per year
  - IVHM research goal is to detect, diagnosis and mitigate lighting strike damage

- When lighting strikes a composite aircraft
  - Structural IR voltages are much greater
  - Magnetic flux penetrates deeper into the fuselage skin
  - New emphasis needed for lightning strike protection (LSP)
    - Structural failure
    - Fuel tank explosion
    - Avionic upset or damage
  - Pilot are often times unaware if an aircraft was struck
  - Visual inspections are performed to look for damage
  - Lightning damage on composites is viewed the same as other mechanical damage

Diagnosis milestone 2.1.2.2 & 1.1.2.1



- Characterize lightning damage on composite aircraft based on the intensity of the lightning current
  - Determine immediate, short term and long term damage
- Damage estimation based on lightning current measurement
  - Reasonable approach for risk assessment
  - Secondary factors will influence accurate damage diagnosis
- Lightning Indirect Effect & HIRF Testing
  - Support NASA Ames prognosis research on MOSFET components
  - Support IVHM V&V redundant computing architecture research

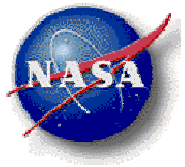
Approach

- Evaluate existing and emerging LSP technologies to determine suitable candidate system for analysis
  - LSP conductor is the primary factor influencing the level of lightning damage on a composite material/structure
- Perform direct effect testing to obtain panels for damage assessments
  - Characterize immediate, short-term or long-term damage
  - Characterize macroscopic and microscopic damage
- Fatigue to failure analysis will be conducted on select damaged panels to quantify mean time to failure assessment
- Identify industry & FAA needs
  - Build collaborations & leverage resources
  - Support relevant & useful research

Results

- Damage is expected
  - Lightning attachment shockwave delamination
  - Lingering current at detachment point causes significant heating
  - intraply and interplay arcing, vaporized resin, broken fiber
  - Damaged fasteners (melted)
  - Pitting and cracking at composite fastener junctions
  - Arcing and pitting at composite joints
  - Lorentz force pulls fibers together
- Damage is damage, repair it
  - Bonded external patch (less than 2mm thickness)
  - Bonded scarf patch (tapered bit used to clean damaged section)
  - Repaint to manufacturer specifications

Results



- Lightning damage is mitigated by LSP layer
  - Conductive layer placed over composite surface
  - Acceptable damage levels are engineered into design
    - Considerations: weight, performance, conductivity, thermal properties, corrosion characteristics & fabrication issues
    - LSP is typically a metal foil or metal mesh (Copper, Bronze or Aluminum)
    - Thicker LSP conductors provide best protection (mass factor)
    - Carbon nanotube materials do not perform as well
    - Hybrid techniques are latest research trend (increase composite conductivity)
  - Flight certified LSP composite designs require large company investments
    - FAA is concerned some proposed LSP systems lack sufficient lightning damage characterizations
    - NASA could play role in producing publicly available data sets to meet industry & FAA needs (standardized composite layup needed)

Results

- Industry Needs
  - Enhance existing LSP composite systems
    - Avionic installations require extra shielding for certification
  - Computational tools to support design trade studies
    - Direct effect damage analysis relies heavily on sample studies
    - Avionic shielding is experimentally determined during installation
  - Improved bonded joints
    - Bonded joints are the major entry point for RF energy into aircraft
    - Challenge problem in Aircraft Ageing & Durability Project

- 2009 IPP proposal submitted for LSP Enhancements
    - Research to improve LSP shielding and develop better computational tools
    - 4 companies, $260K industry contribution, $40K IVHM investment
    - IVHM Project support, HQ IPP funding not available

Results

- NASA Needs
  - Proper selection of composite LSP system for damage analysis
    - LSP conductor is the primary factor preventing damage
  - Other factors may influence level of damage from strike
    - Temperature, environmental age & moisture content
    - Secondary influences may cause significant variation in results

- NASA Tech Briefs
  - July 2009, Needs Article published for LSP enhancements
    - 10 companies identified as potential industry collaborators

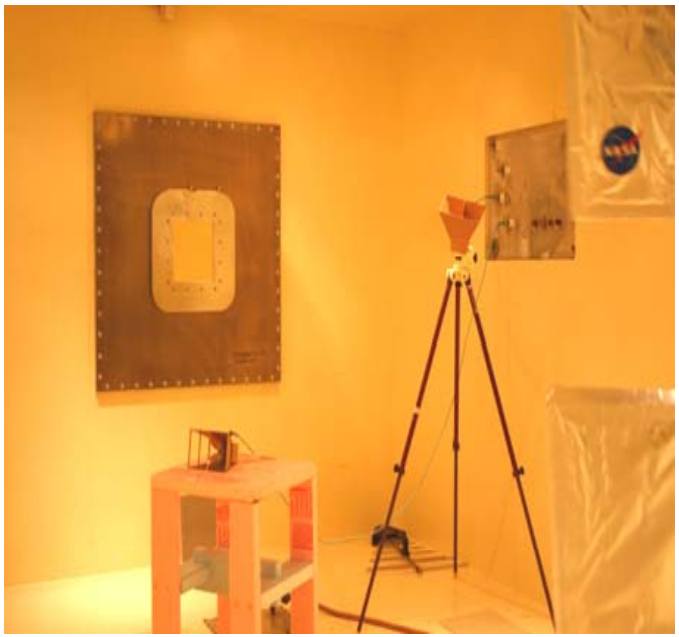
- 2010 Congressional Budget Line Item for $3 Million to AFRL to study LSP for commercial composite aircraft
  - Contacted AFRL POC for collaboration

Results

- Awarded Phase III SBIR to acquire composite LSP test panels ($50K)
  - Direct effect tests conducted in March 2009 on select composite panels (Aluminum mesh & Carbon Nanotubes)
    - Study included Surlyn self healing material as part of LSP
    - No dielectric (except paint/primer) can be applied over the LSP
  - Electrical characterizations are being conducted at Langley
    - RF Shielding effectiveness measurements
    - Surface current mapping
    - Eddy current measurements
  - Final composite panel shipment expected in late November
  - Direct Effect tests tentatively planned for January 2010
    - Testing will include lightning current sensor evaluation

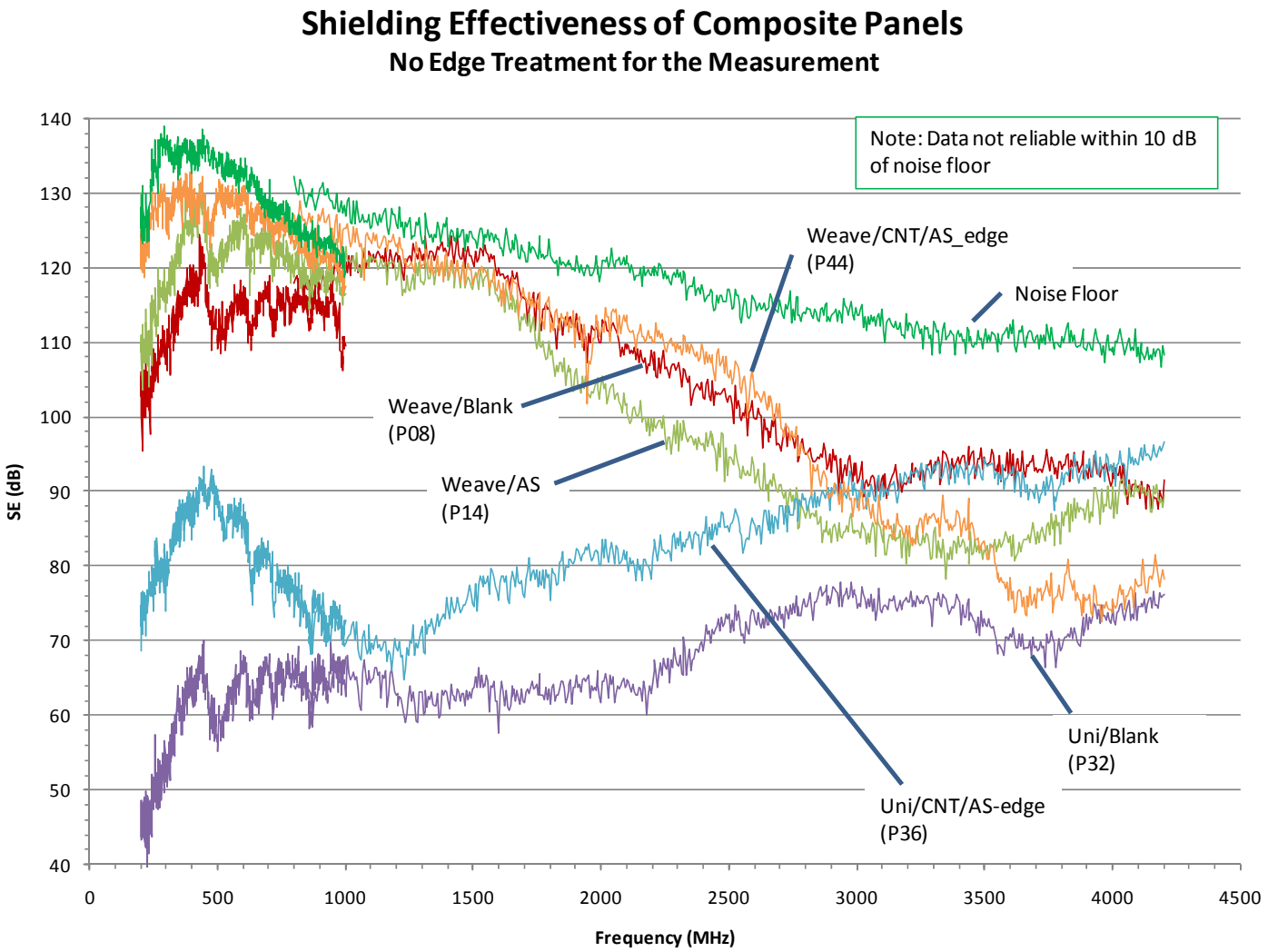
Results

RF Shielding Effectiveness (SE) Measurements



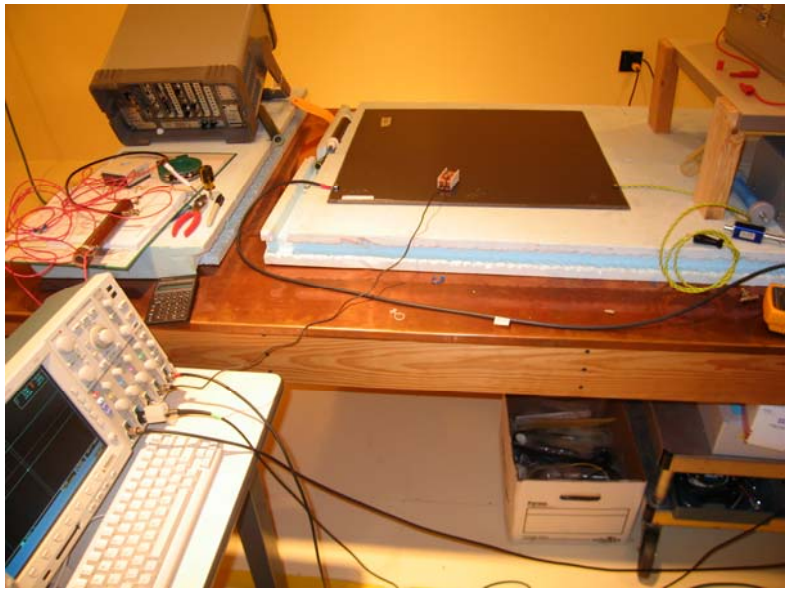
- Mode stirring will vary polarization and incidence angle to provide average SE
- NIST Procedure developed by Holloway
- Accuracy determined by chamber uniformity
- Frequency capability from 200MHz -18GHz
- Explore improved edge treatment methods
- Panels will be characterized pre and post direct effect lightning damage
- Conducting SE measurements in HIRF chamber provides ability to increase transmit power to improve measurement sensitivity.
- Anticipate greater than 120dB isolation between chambers.
- Provide well quantified results to modeling community to support lightning computational activities.

Results


Shielding Effectiveness of Composite Panels
No Edge Treatment for the Measurement
Note: Data not reliable within 10 dB of noise floor
Weave/CNT/AS_edge (P44)
Noise Floor
Weave/Blank (P08)
Weave/AS (P14)
Uni/Blank (P32)
Uni/CNT/AS-edge (P36)
SE (dB)
Frequency (MHz)
140
130
120
110
100
90
80
70
60
50
40
0
500
1000
1500
2000
2500
3000
3500
4000
4500

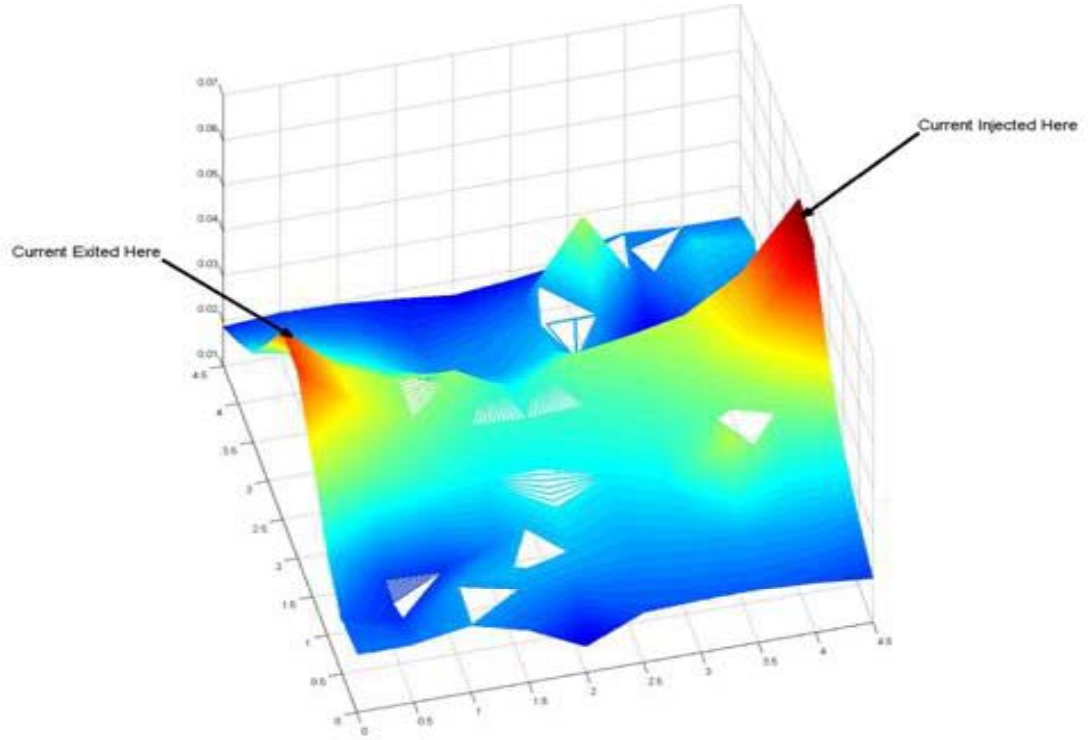
Surface Current Mapping

- Induce indirect effect electrical currents using simulated lightning waveforms in on the panel edges.
- Correlate Time & Frequency domain techniques.
- Evaluate lighting detection sensors.
- Captured waveforms will provide insight into electrical properties which influence lightning current propagation.



- Various techniques will be explored to determine the best method to expose the carbon fibers for current injection.
- Provide measurement results to modeling community.

Surface Current Mapping (Preliminary Results)



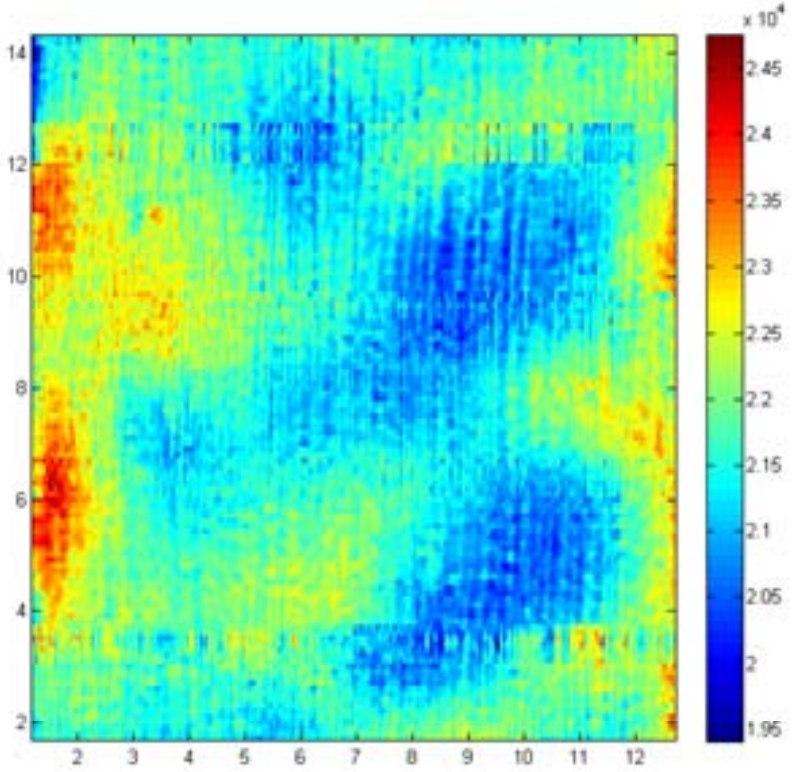
Distance in inches are shown on the x and y axis.
Current density is shown in the z axis.

Eddy Current Measurements

- Monitor voltage as a function of position from an electromagnetic coil moved along the surface of a composite panel to calculate surface impedance parameters.
- Identify irregularities in the lightning protection conductor or composite structure beneath.
- Research sponsored by Aircraft Aging and Durability (AAD) Project

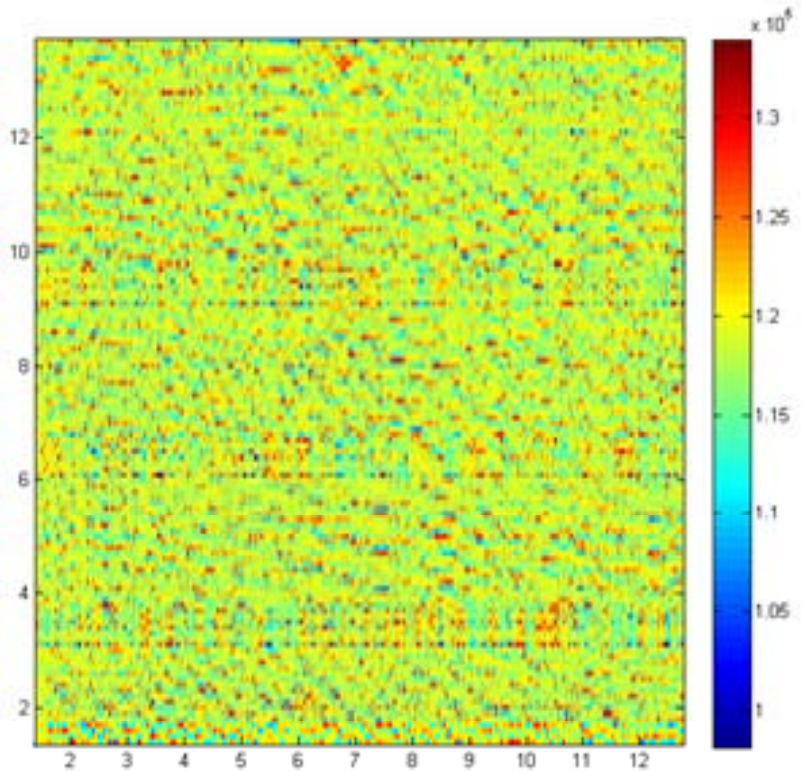
- Test results will be correlated with other nondestructive evaluation (NDE) techniques for anomaly detection.

Eddy Current Test Results



Top Surface
Aluminum Mesh

1.95×10^4 $(ohm*m)^{-1}$ to 2.45×10^4 $(ohm*m)^{-1}$

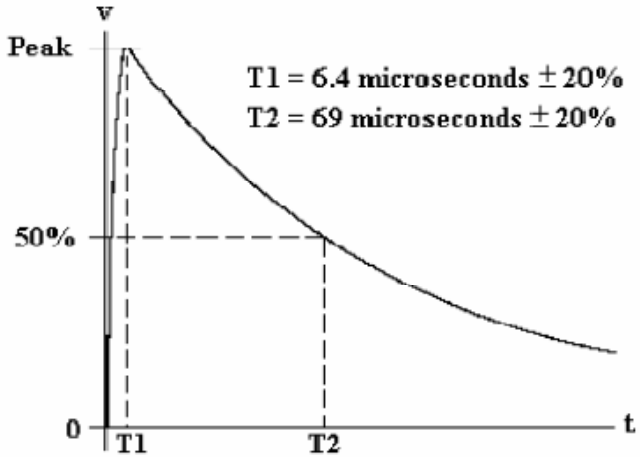


Bottom Surface
Composite Weave

1×10^5 $(ohm*m)^{-1}$ to 1.3×10^5 $(ohm*m)^{-1}$

Lightning Pin Injection Testing on Power-MOSFETs

- Research lead by NASA Ames
- LaRC HIRF Facility personnel developed test procedures to expose MOSFETS to lightning test waveforms 3, 4 & 5
- MOSFETS tested in OFF State, Jan 2009
- MOSFETS tested in On State, May 2009
- Lightning equipment upgraded in 2009
- "Lightning Pin Injection Testing on MOSFETS", NASA/TM-2009-215794 ", Sept. 2009
- "Effects of Lightning Injection on Power-MOSFETs", PHM Society Conference, Oct. 2009.



RTCA/DO-160E Section 22
Voltage Waveform

Conclusions

- LSP conductors are designed to minimize damage from a strike
- Lightning damage is considered safe as mechanical damage, patch it
- On-board lightning current measurements is a reasonable approach for obtaining damage risk assessment for composite damage.
  - Secondary factors may prevent accurate damage diagnosis
- Selection of appropriate LSP composite material/structure is required to perform damage assessments
- Electrical characterizations & direct effect lightning testing will be performed on selected LSP composite panels
- FAA, AFRL & Industry collaborations will continue
  - Leverage the ARFL LSP research as much as possible
  - Develop standardized composite layup for with Boeing for LSP evaluations
- Participation in certification committees
  - SAE AE2 Lightning Committee
  - RTCA SC-135, WG 20 & 21

Next Steps

- Investigate applicability of Open Circuit Resonant Sensors
- Multifunctional use: composite damage, stress, strain, air pressure, temperature
- Measure impedance of surrounding material
- Challenges: poor performance on conductive surfaces

Typical Expected Theoretical Response