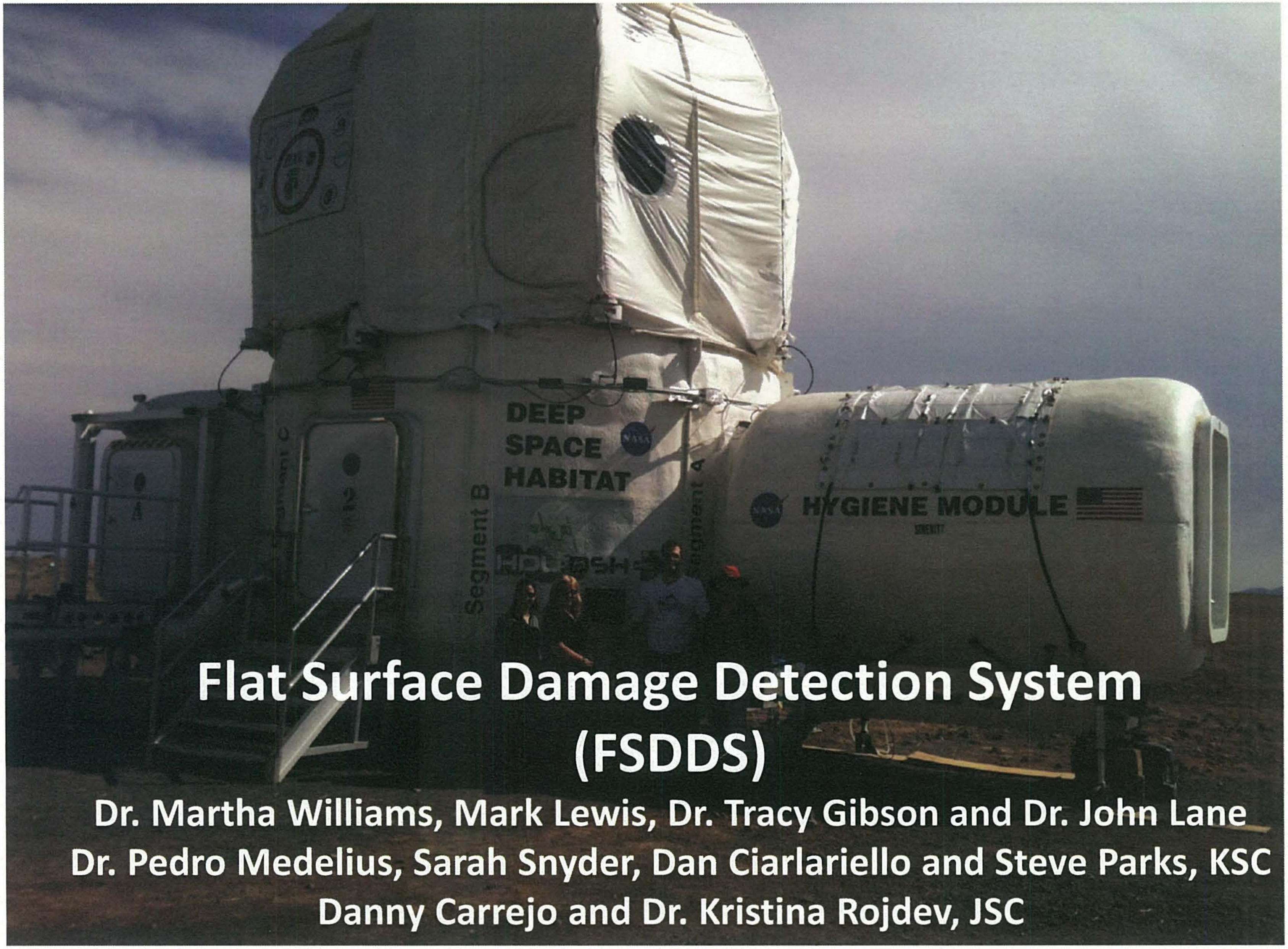


Flat Surface Damage Detection System (FSDDS)

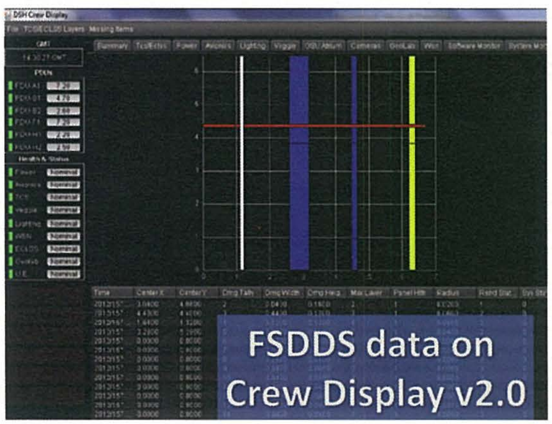
Dr. Martha Williams, Mark Lewis, Dr. Tracy Gibson and Dr. John Lane
Dr. Pedro Medelius, Sarah Snyder, Dan Ciarlariello and Steve Parks, KSC
Danny Carrejo and Dr. Kristina Rojdev, JSC

Background

- KSC has been working in self healing and damage detection technologies for more than 10 years. Knowledge leveraged from the development of wiring damage detection systems.
- KSC IRTD FY11 funded project for development of hardware and software; used internal ink-jet printing technology for printing conductive traces
- Successfully demonstrated as a stand alone technology during 2011 D-RATS under IRTD.
- AES funded software modification allowed for communication with HDU avionics crew display which was demonstrated remotely (KSC to JSC) during 2012 integration testing.
- Integrated FSDDS system and stand alone multi-panel systems (AES funded) were demonstrated remotely and at JSC, Mission Operations Test using Space Network Research Federation (SNRF) network in 2012.
- FY13, FSDDS multi-panel integration with JSC and SNRF network
- Technology can allow for integration with other complementary damage detection systems
- Full patent application filed in 2012

DSH Technology & Innovations
Flat Surface Damage Detection System (FSDDS)

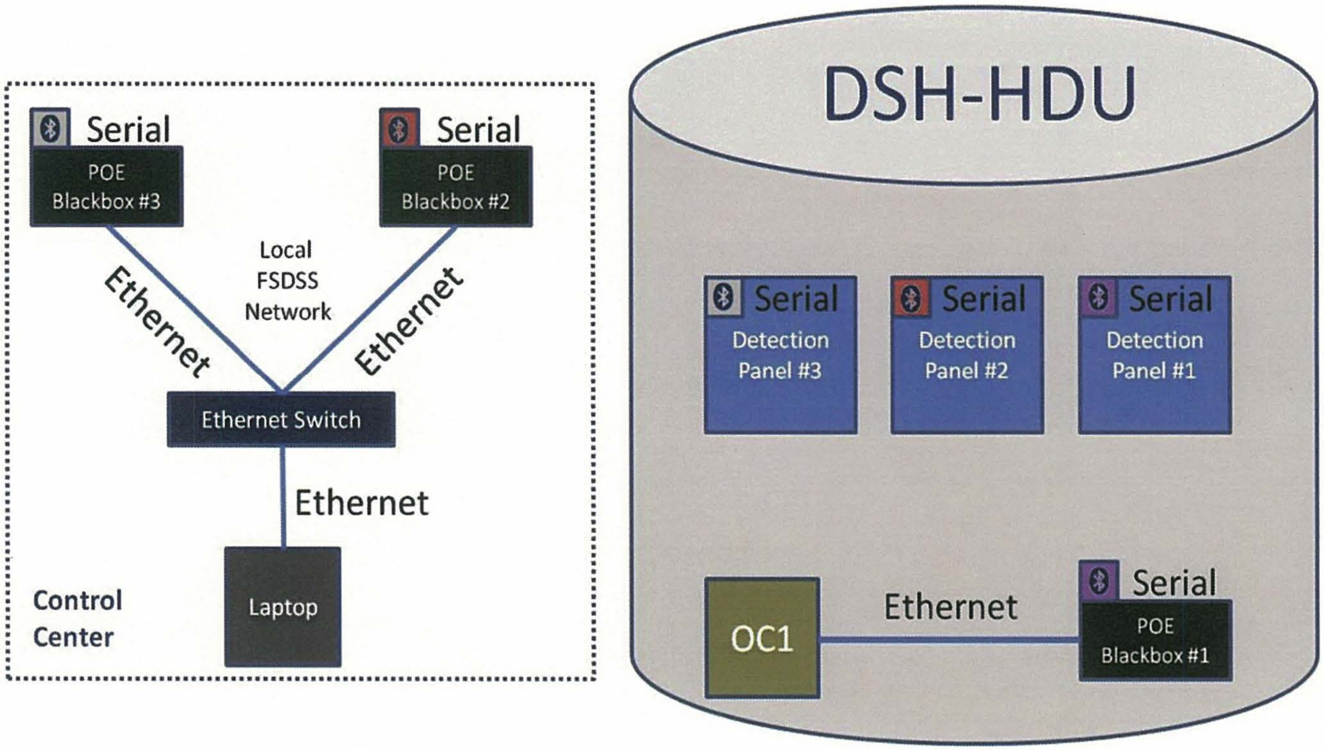
FSDDS sensory panels system at MOT 2012



FSDDS data on crew display during remote integration testing 2012

- **Flat Surface Damage Detection**: The Flat Surface Damage Detection system (FSDDS) is a sensory system that is capable of detecting impact damages to surfaces utilizing a novel sensor system. This system will provide the ability to monitor the integrity of an inflatable habitat during in situ system health monitoring.
- The system consists of three main custom designed subsystems: the multi-layer sensing panel, the embedded monitoring system, and the graphical user interface (GUI).
- The GUI LABVIEW software uses a custom developed damage detection algorithm to determine the damage location based on the sequence of broken sensing lines. It estimates the damage size, the maximum depth, and plots the damage location on a graph.
- Successfully demonstrated as a stand alone technology during 2011 D-RATS.
- Software modification also allowed for communication with HDU avionics crew display which was demonstrated remotely (KSC to JSC) during 2012 integration testing.
- Integrated FSDDS system and stand alone multi-panel systems were demonstrated remotely and at JSC, Mission Operations Test using Space Network Research Federation (SNRF) network in 2012.
- FY13, FSDDS multi-panel integration with JSC and SNRF network
- Technology can allow for integration with other complementary damage detection systems

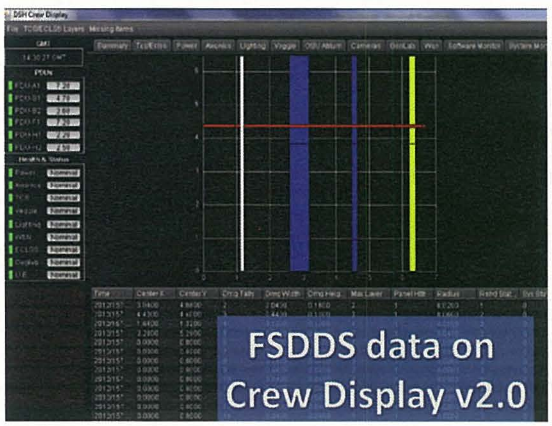
Raw damage data is transmitted serially and converted to Ethernet utilizing a Power over Ethernet Black Box. Each POE Blackbox has a unique IP address and Bluetooth device that is paired with a Bluetooth device on a unique detection panel, allowing monitoring of specific detection panels. The integrated panel (Panel #1) was monitored using an IPad running the crew display application. The stand-alone panels (Panels #2 and #3) were monitored using a laptop running the GUI in the control center.



Block Diagram Pictorial Representation of the Communication Layout of the FSDDS Stand-Alone and Multi-panel Systems for FY12

DSH Technology & Innovations
Flat Surface Damage Detection System (FSDDS) FY12-F13 Status

FSDDS sensory panels system at MOT 2012



FSDDS data on crew display during remote integration testing 2012

- **Flat Surface Damage Detection**: The Flat Surface Damage Detection system (FSDDS) is a sensory system that is capable of detecting impact damages to surfaces utilizing a novel sensor system. This system will provide the ability to monitor the integrity of an inflatable habitat during in situ system health monitoring.
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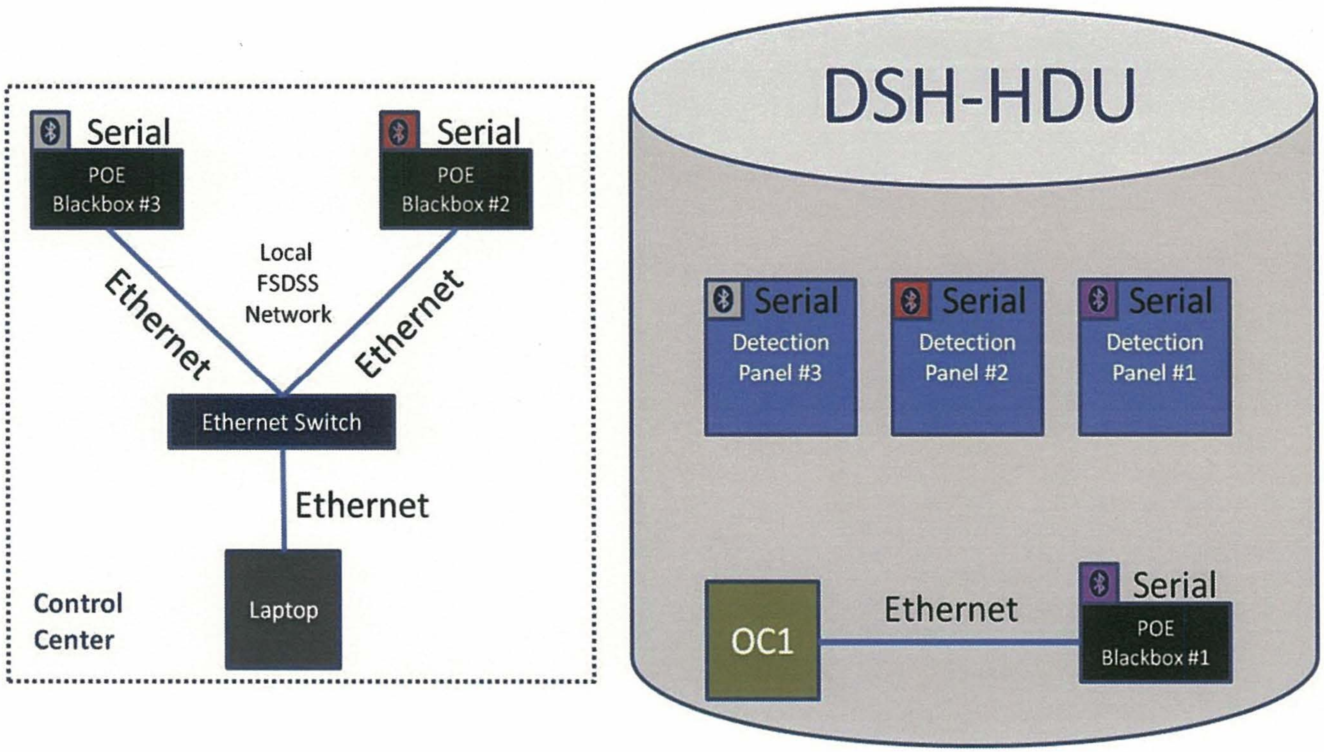
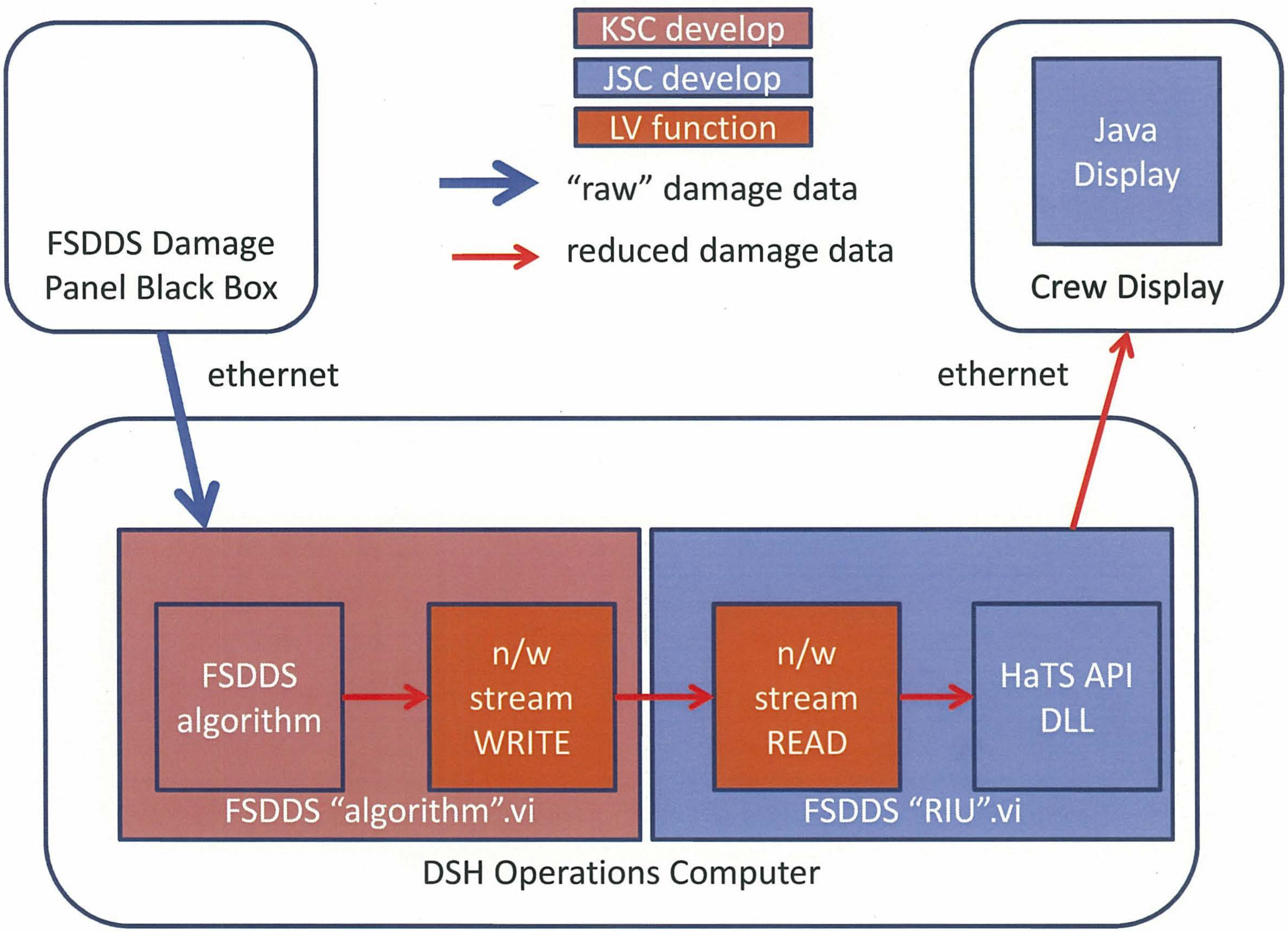


Block Diagram Pictorial Representation of the Communication Layout of the FSDDS Stand-Alone and Multi-panel Systems for FY12

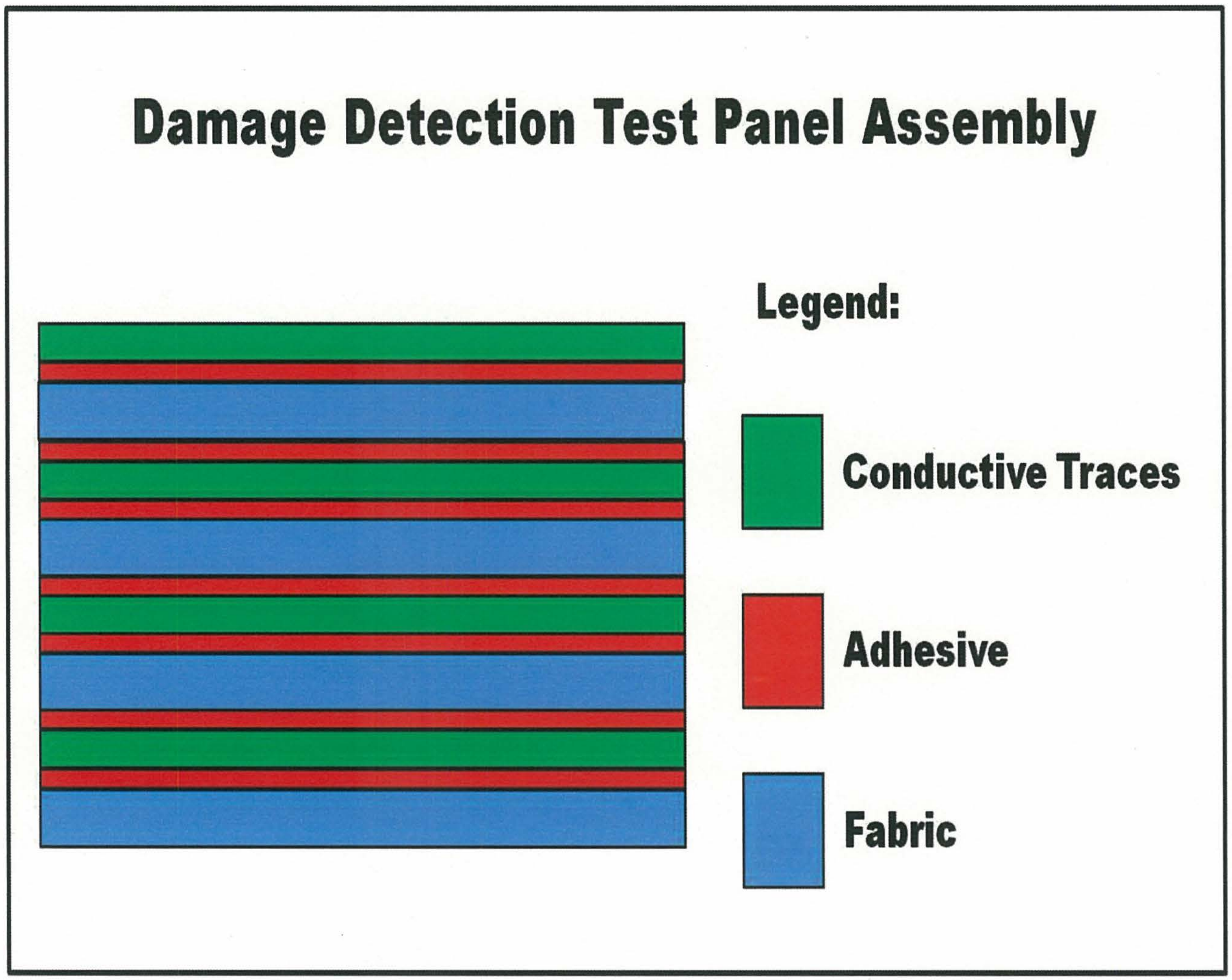
FSDDS DSH software interfaces



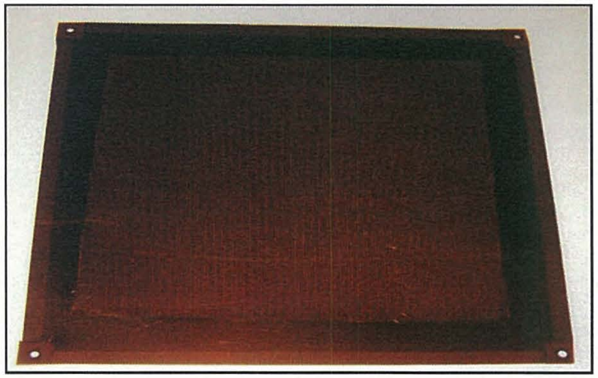
FSDDS Operations Summary

- The operation of the damage detection system is based on the use of parallel **conductive traces placed on a firm or flexible surface**.
- Several detection layers can be implemented, **where alternate layers are arranged in an orthogonal direction with respect to adjacent layers**. The orthogonal arrangement allows for pinpointing the exact location of the damage to the surface under test. **Multiple detection layers allow for the calculation of the depth of the damage** to the surface under test.
- **Minimizes the use of active electronic components** to reduce the risk of incorrect operation due to radiation factors. The **FSDSS circuit uses only two active components: a microcontroller, and a serial port bidirectional driver/receiver**. Wireless communication.
- **Microcontroller is used to inject and monitor test signals to determine the integrity of the sensing lines**
- **The data is transmitted wirelessly to a central commuting system**
- **A GUI monitors and controls the system.**

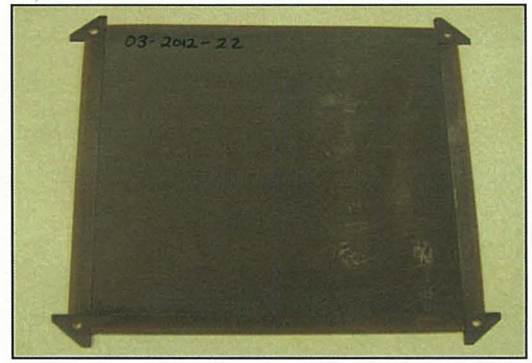
FSDDS Detection Panel Design

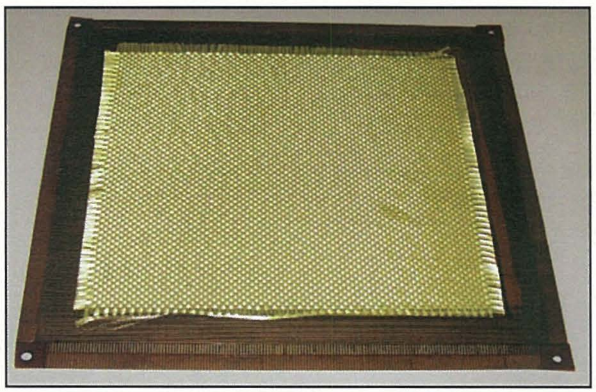


Damage Detection Panel Fabrication

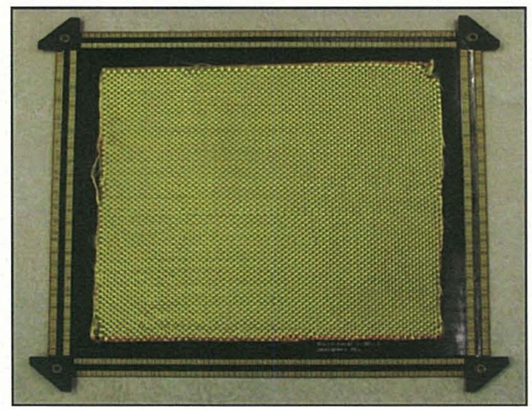


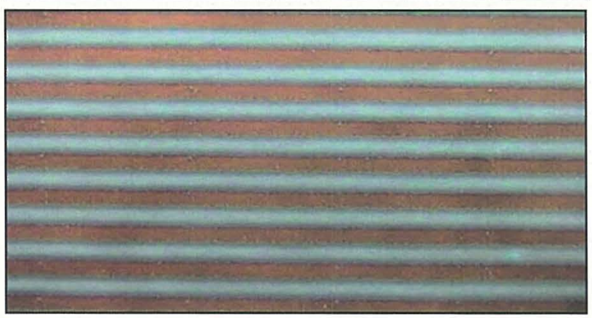
Insulation side of laboratory (left) and commercially (right) printed circuitry



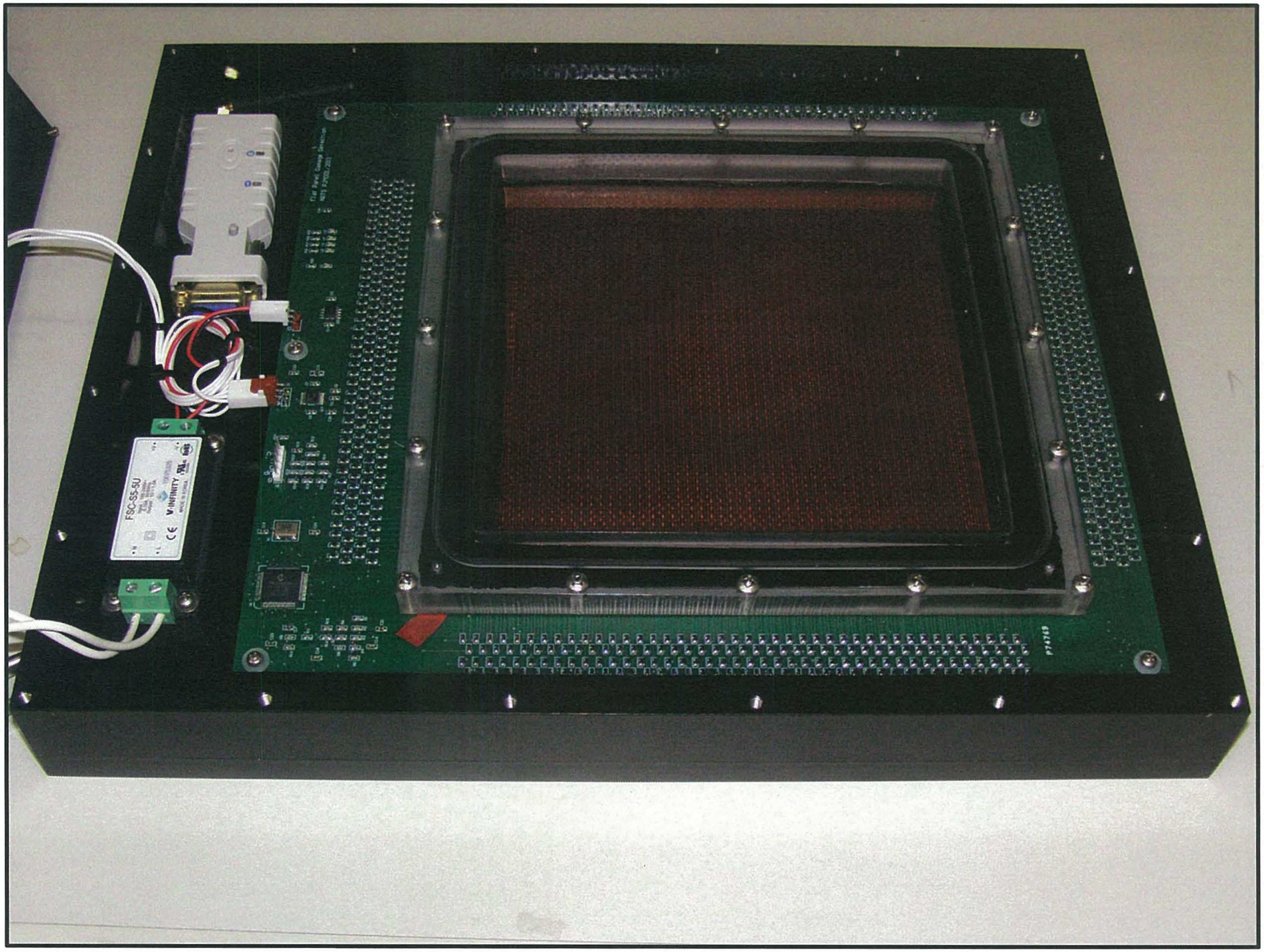


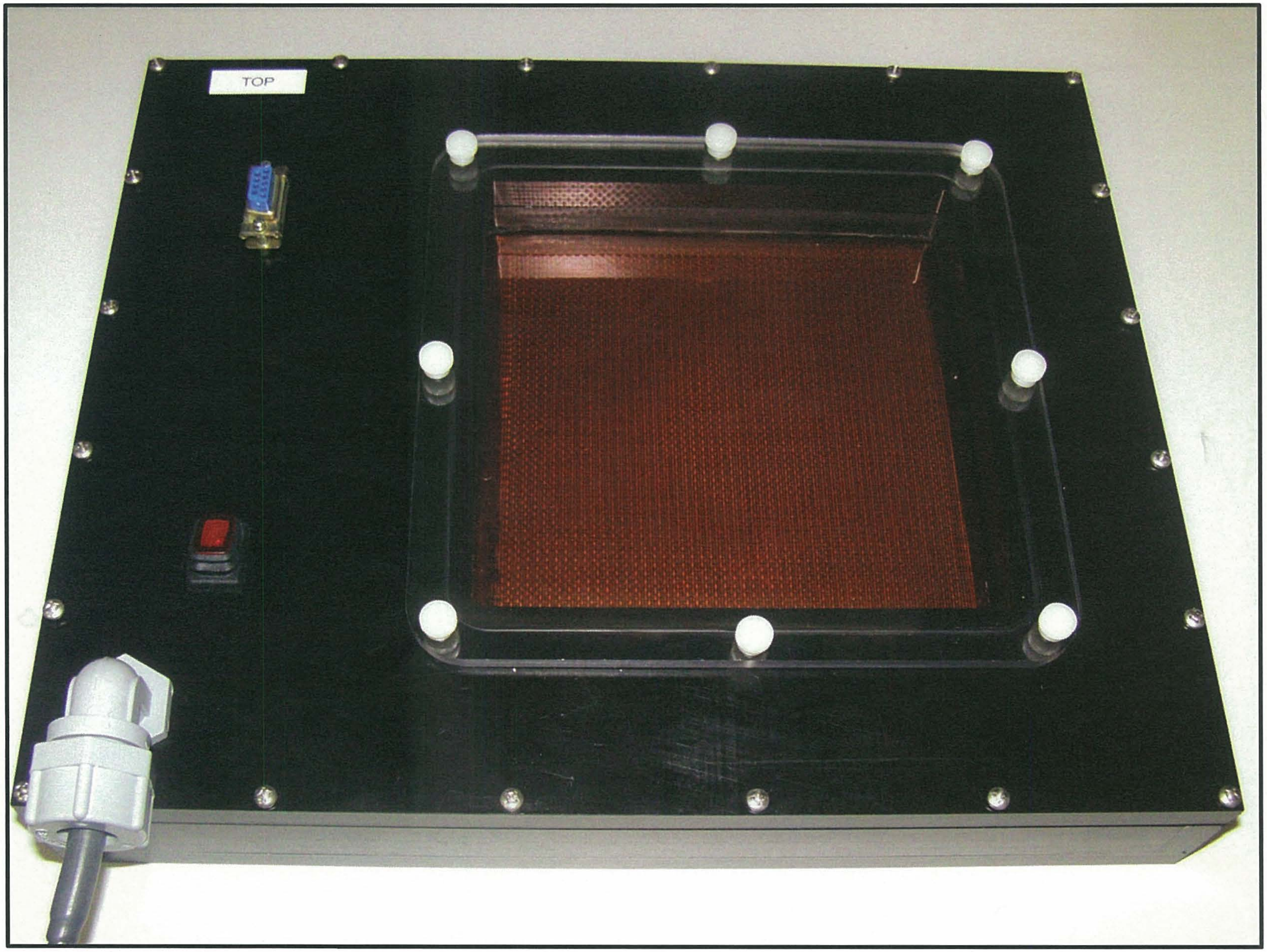
Fabric side of laboratory printed and assembled multi-layered system (left) and commercially (right) printed circuitry and laboratory assembled multi-layered system (right)

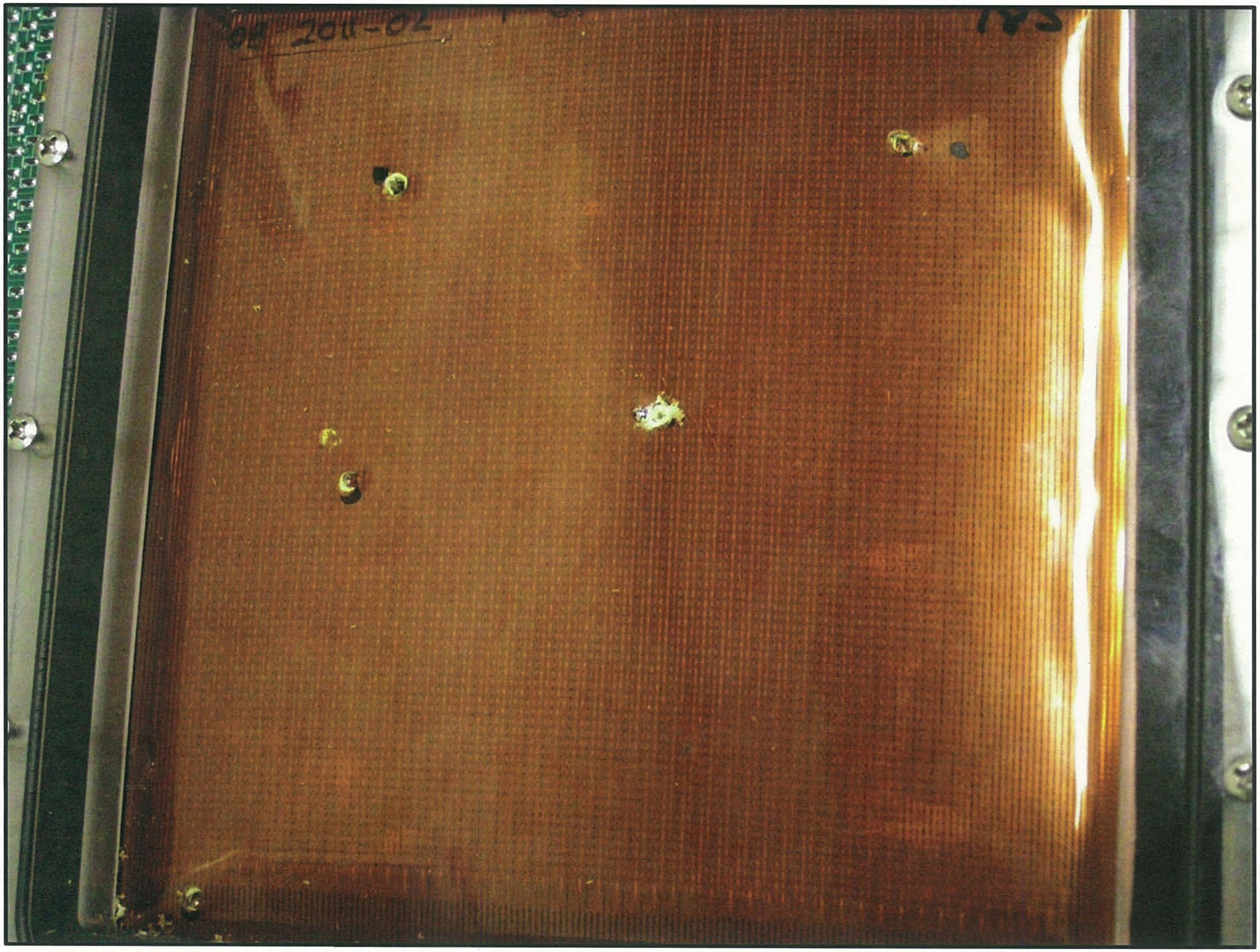


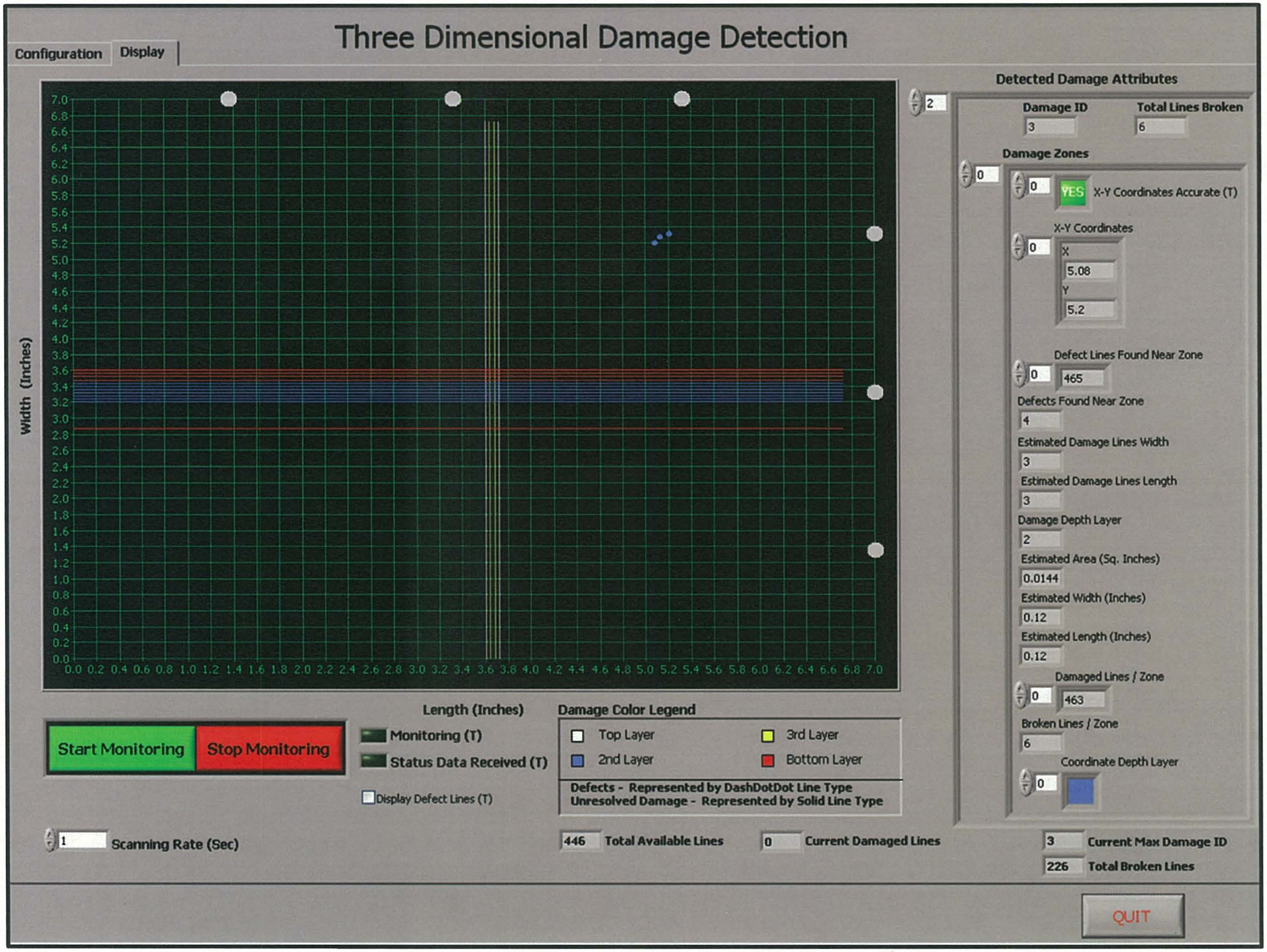


Close up of laboratory ink-jet printed circuitry(left)

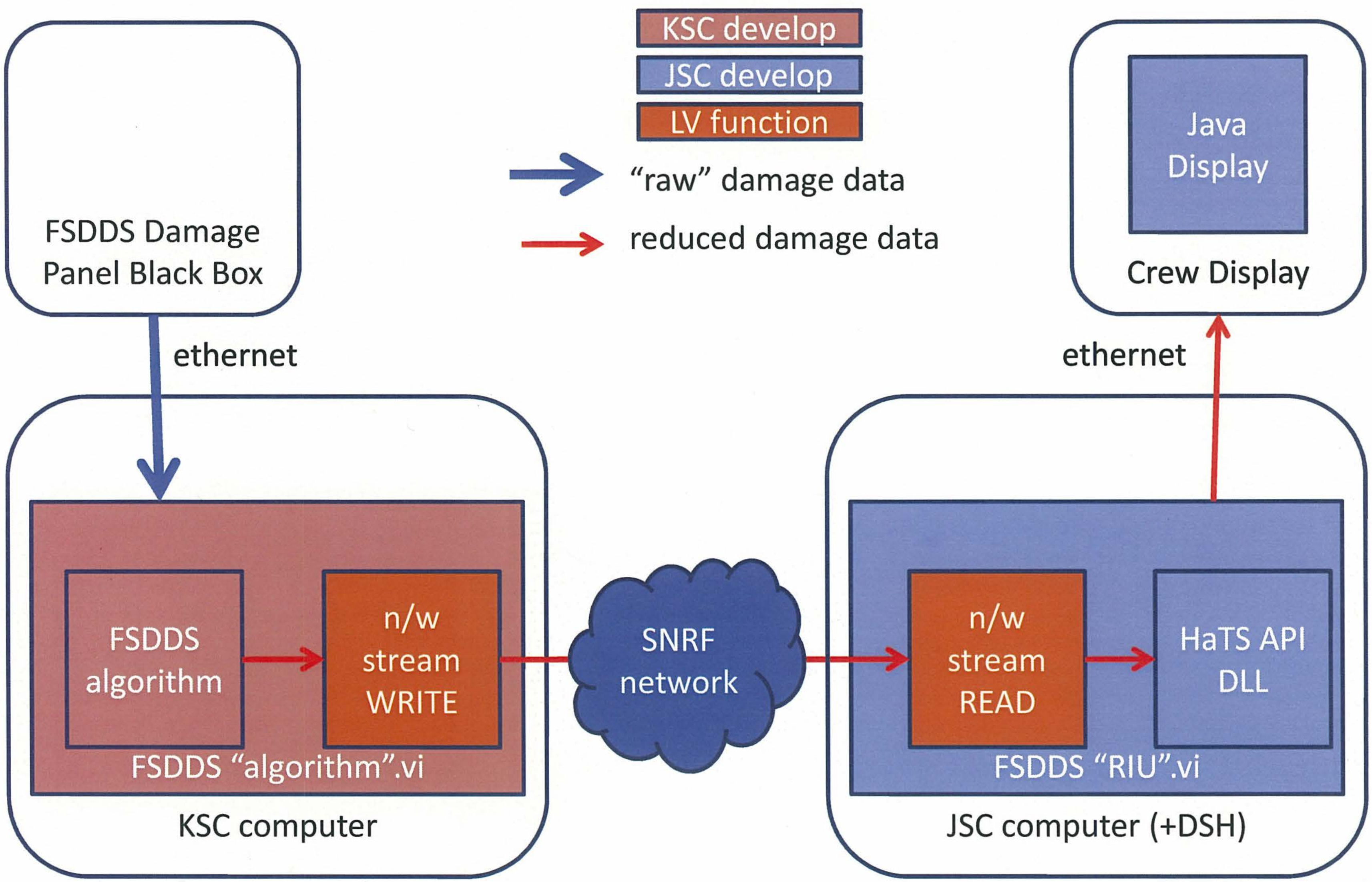

FSC-S5-5U
V-INFINITY

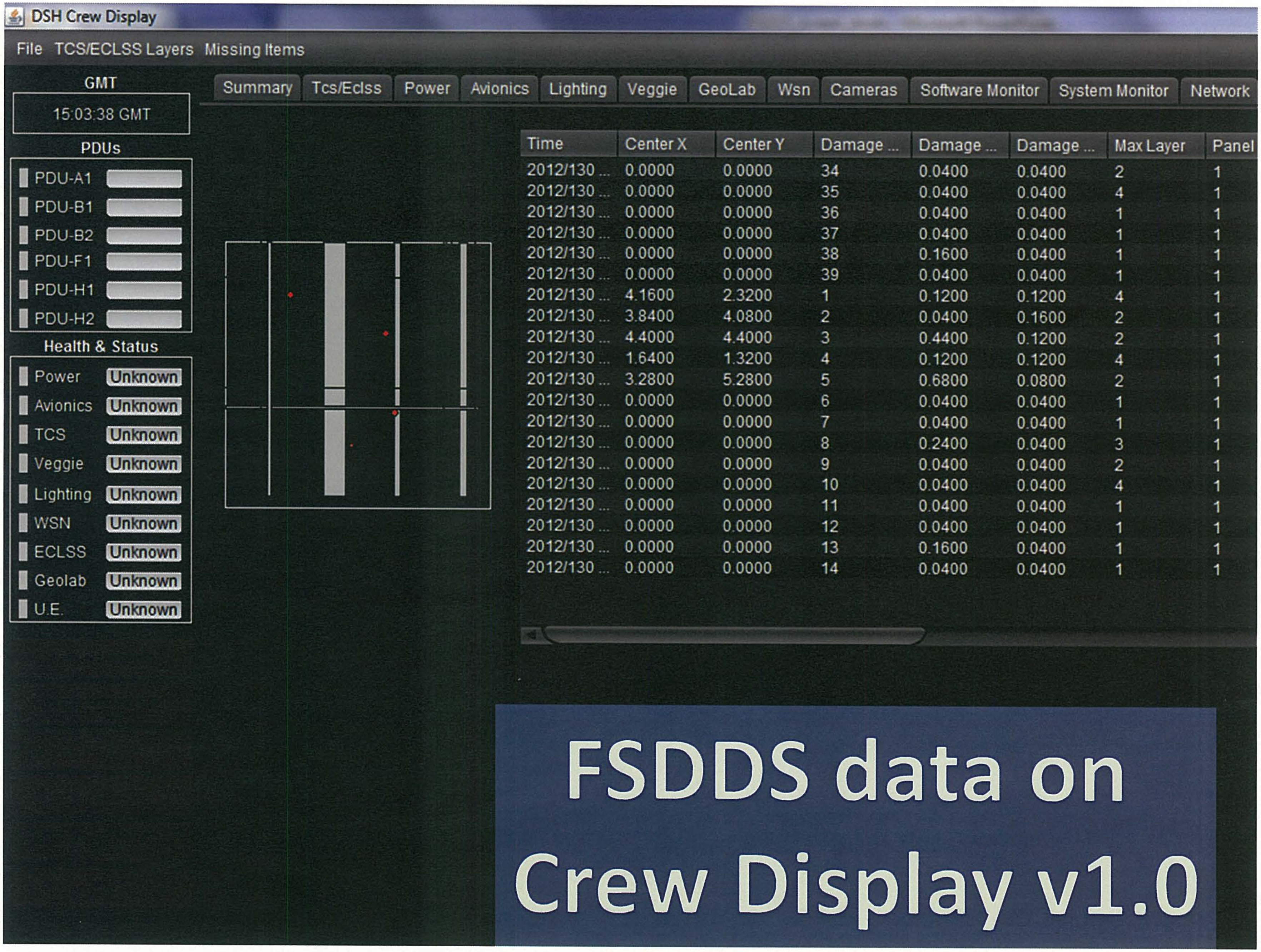

TOP

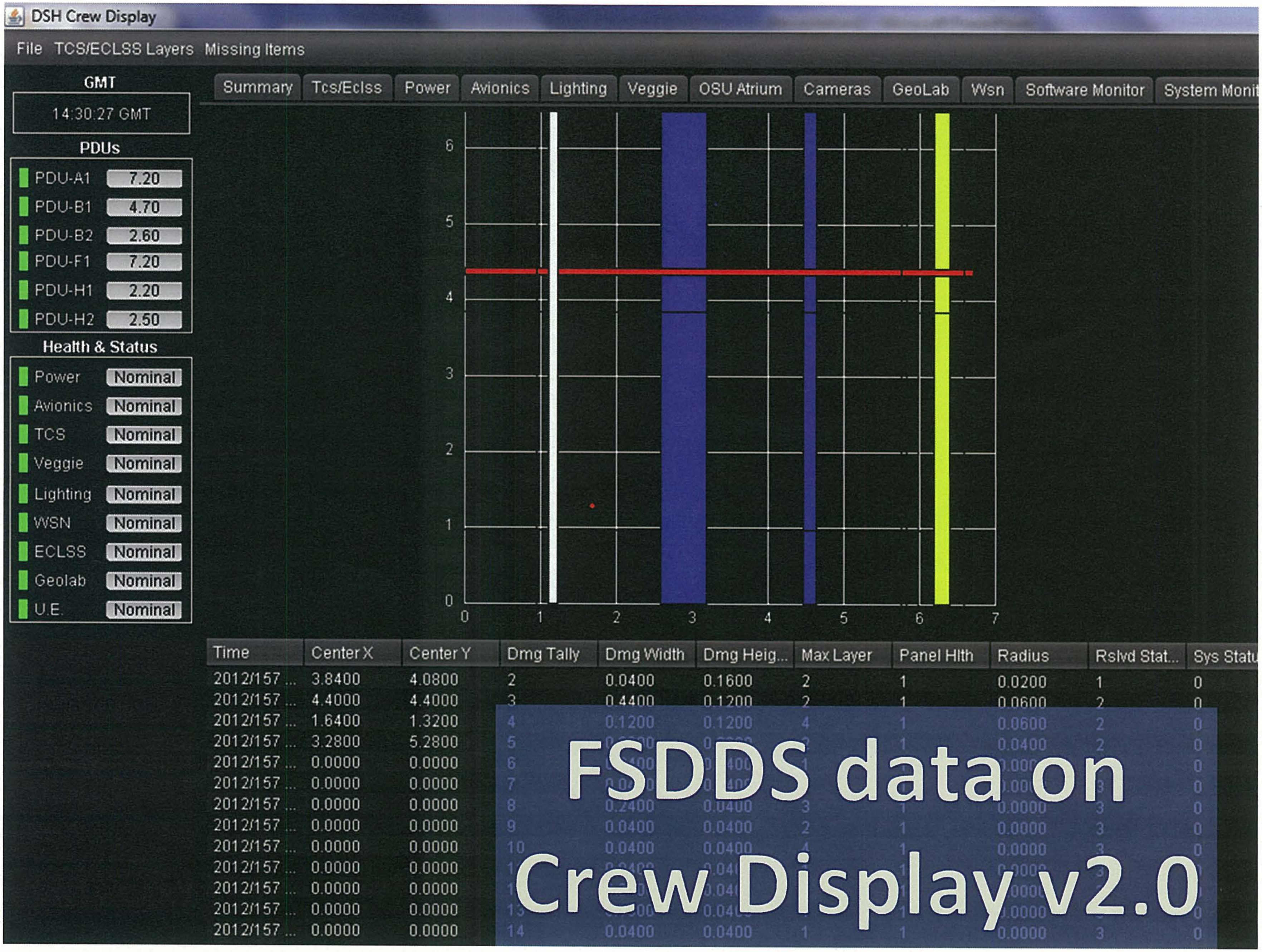



Three Dimensional Damage Detection
Configuration
Display
Detected Damage Attributes
2
Damage ID
3
Total Lines Broken
6
Damage Zones
0
0
YES
X-Y Coordinates Accurate (T)
X-Y Coordinates
0
X
5.08
Y
5.2
Defect Lines Found Near Zone
0
465
Defects Found Near Zone
4
Estimated Damage Lines Width
3
Estimated Damage Lines Length
3
Damage Depth Layer
2
Estimated Area (Sq. Inches)
0.0144
Estimated Width (Inches)
0.12
Estimated Length (Inches)
0.12
Damaged Lines / Zone
0
463
Broken Lines / Zone
6
Coordinate Depth Layer
0
Width (Inches)
Length (Inches)
Start Monitoring
Stop Monitoring
Monitoring (T)
Status Data Received (T)
Display Defect Lines (T)
Damage Color Legend
Top Layer
3rd Layer
2nd Layer
Bottom Layer
Defects - Represented by DashDotDot Line Type
Unresolved Damage - Represented by Solid Line Type
1
Scanning Rate (Sec)
446
Total Available Lines
0
Current Damaged Lines
3
Current Max Damage ID
226
Total Broken Lines
QUIT

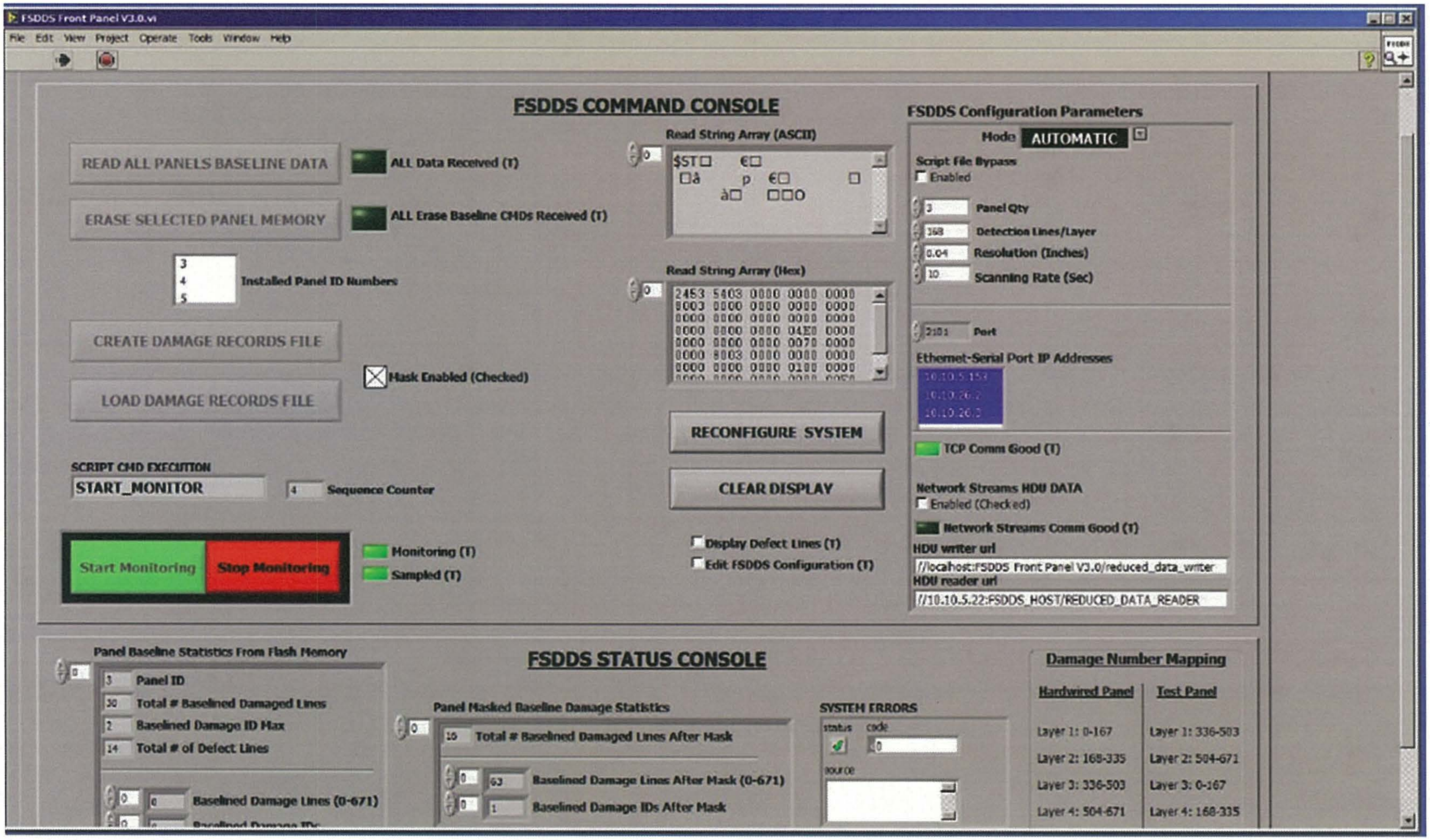
FSDDS DSH test configuration



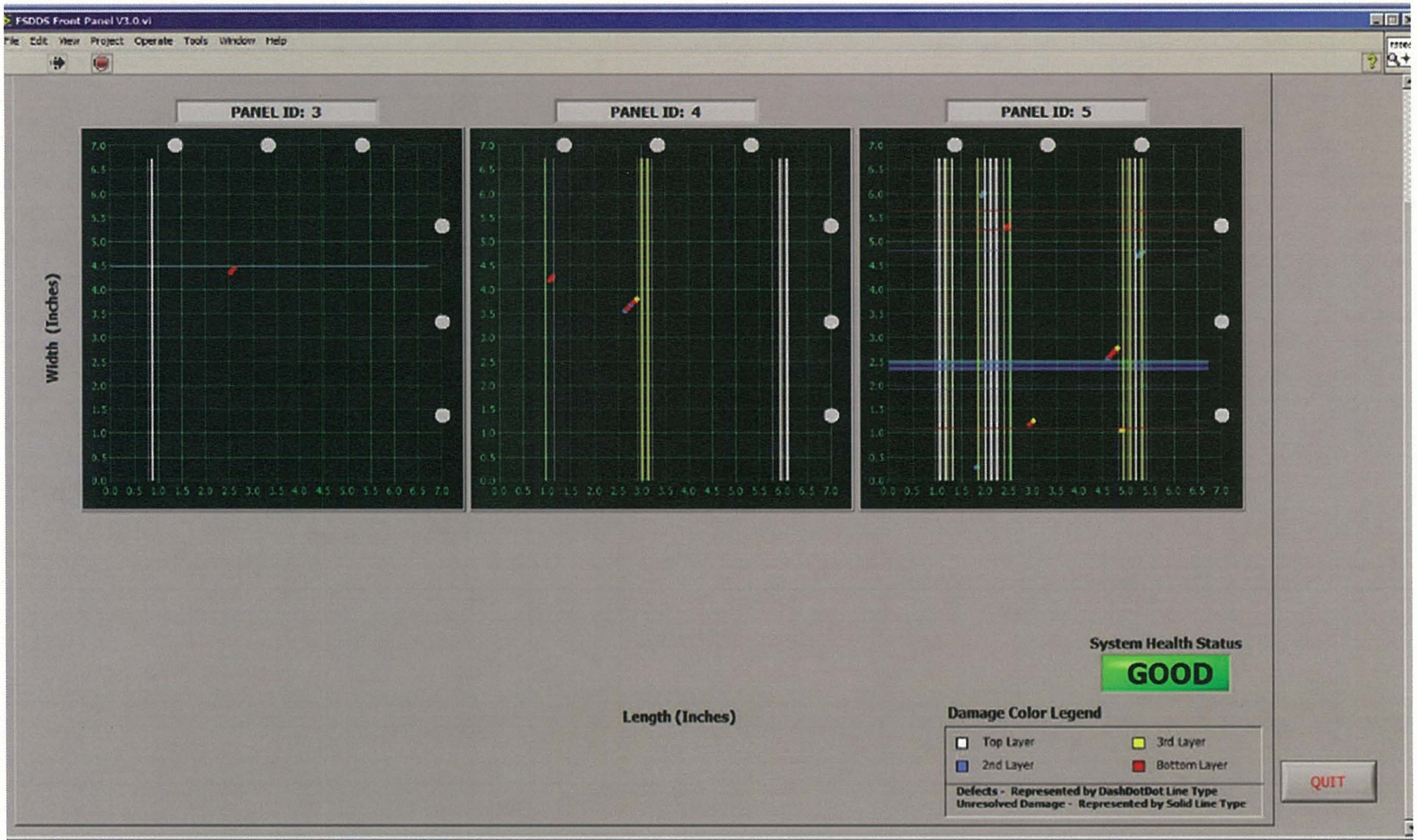

DSH Crew Display
File TCS/ECLSS Layers Missing Items
GMT
15:03:38 GMT
PDUs
PDU-A1
PDU-B1
PDU-B2
PDU-F1
PDU-H1
PDU-H2
Health & Status
Power Unknown
Avionics Unknown
TCS Unknown
Veggie Unknown
Lighting Unknown
WSN Unknown
ECLSS Unknown
Geolab Unknown
U.E. Unknown
Summary Tcs/Eclss Power Avionics Lighting Veggie GeoLab Wsn Cameras Software Monitor System Monitor Network
Time Center X Center Y Damage ... Damage ... Damage ... Max Layer Panel
2012/130 ... 0.0000 0.0000 34 0.0400 0.0400 2 1
2012/130 ... 0.0000 0.0000 35 0.0400 0.0400 4 1
2012/130 ... 0.0000 0.0000 36 0.0400 0.0400 1 1
2012/130 ... 0.0000 0.0000 37 0.0400 0.0400 1 1
2012/130 ... 0.0000 0.0000 38 0.1600 0.0400 1 1
2012/130 ... 0.0000 0.0000 39 0.0400 0.0400 1 1
2012/130 ... 4.1600 2.3200 1 0.1200 0.1200 4 1
2012/130 ... 3.8400 4.0800 2 0.0400 0.1600 2 1
2012/130 ... 4.4000 4.4000 3 0.4400 0.1200 2 1
2012/130 ... 1.6400 1.3200 4 0.1200 0.1200 4 1
2012/130 ... 3.2800 5.2800 5 0.6800 0.0800 2 1
2012/130 ... 0.0000 0.0000 6 0.0400 0.0400 1 1
2012/130 ... 0.0000 0.0000 7 0.0400 0.0400 1 1
2012/130 ... 0.0000 0.0000 8 0.2400 0.0400 3 1
2012/130 ... 0.0000 0.0000 9 0.0400 0.0400 2 1
2012/130 ... 0.0000 0.0000 10 0.0400 0.0400 4 1
2012/130 ... 0.0000 0.0000 11 0.0400 0.0400 1 1
2012/130 ... 0.0000 0.0000 12 0.0400 0.0400 1 1
2012/130 ... 0.0000 0.0000 13 0.1600 0.0400 1 1
2012/130 ... 0.0000 0.0000 14 0.0400 0.0400 1 1
FSDDS data on Crew Display v1.0


FSDDS data on Crew Display v2.0
DSH Crew Display
File TCS/ECLSS Layers Missing Items
Summary Tcs/Eclss Power Avionics Lighting Veggie OSU Atrium Cameras GeoLab Wsn Software Monitor System Monit
GMT
14:30:27 GMT
PDUs
PDU-A1 7.20
PDU-B1 4.70
PDU-B2 2.60
PDU-F1 7.20
PDU-H1 2.20
PDU-H2 2.50
Health & Status
Power Nominal
Avionics Nominal
TCS Nominal
Veggie Nominal
Lighting Nominal
WSN Nominal
ECLSS Nominal
Geolab Nominal
U.E. Nominal
Time Center X Center Y Dmg Tally Dmg Width Dmg Heig... Max Layer Panel Hlth Radius Rslvd Stat... Sys Statu
2012/157 ... 3.8400 4.0800 2 0.0400 0.1600 2 1 0.0200 1 0
2012/157 ... 4.4000 4.4000 3 0.4400 0.1200 2 1 0.0600 2 0
2012/157 ... 1.6400 1.3200
2012/157 ... 3.2800 5.2800
2012/157 ... 0.0000 0.0000

FSDDS Display Screen of Simultaneous (KSC and JSC) and Remote monitoring of multiple detection panels



FSDDS Labview Display of Multi-Panel Systems



Matrix Math Software upgrade being considered

Back up slides

TECH BRIEFS

Damage Detection and Self-Repair in Inflatable/Deployable Structures

NASA's Jet Propulsion Laboratory
Sunday, March 01 2009

Integrated sensors and self-repairing materials provide structural health management.

Inflatable/deployable structures are under consideration for applications as varied as expansion modules for the International Space Station to destinations for space tourism to habitats for the lunar surface. Monitoring and maintaining the integrity of the physical structure is critical, particularly since these structures rely on non-traditional engineering materials such as fabrics, foams, and elastomeric polymers to provide the primary protection for the human crew. The closely related prior concept of monitoring structural integrity by use of built-in or permanently attached sensors has been applied to structures made of such standard engineering materials as metals, alloys, and rigid composites. To effect monitoring of flexible structures comprised mainly of soft goods, however, it will be necessary to solve a different set of problems — especially those of integrating power and data-transfer cabling that can withstand, and not unduly interfere with, stowage and subsequent deployment of the structures. By incorporating capabilities for self-repair along with capabilities for structural health monitoring, successful implementation of these technologies would be a significant step toward semi-autonomous structures, which need little human intervention to maintain. This would not only increase the safety of these structures, but also reduce the inspection and maintenance costs associated with more conventional structures.

A series of proof-of-concept technology sensing and self-repair technologies have recently been developed and tested individually, for future integration into a full health management system for inflatable/deployable structures. With further development, these technologies could be applied individually or as part of an entire system, depending on the particular architecture of the structure or on the specific mission needs. The technologies include:

- Arrays of thin-film capacitive or inductive sensors, made of a flexible circuit material that can be integrated into an inflatable/deployable structure for use in detecting the location and extent of damage. Damage manifests itself as changes in inductance or capacitance in elements of the sensor array.
- Strain gauges made from thin films of amorphous silicon for monitoring the integrity of thin, flexible structures. To reduce the amount of wiring required, thin-film transistors are used to construct an addressable, matrixed array of sensors allowing selection and readout of specific sensors in the array.
- Wireless sensors and passive (no-power) radio-frequency identification sensor tags to provide additional sensing capabilities such as strain sensing, temperature sensing, and impact or leak detection, without the need for data and power cables.
- Self-repairing elastomeric materials (such as those used to construct the bladder of a habitat), which incorporate microcapsules filled with a monomer resin and a small amount of a polymerization catalyst. Upon damage to the material, some of the capsules burst and release the monomer, becoming polymerized after making contact with the embedded catalyst and thus effecting repair of the damage.
- Sensory and self-repair features will eventually be combined into the structure to effect a unified structural health maintenance system. Sensors will alert humans to initial damage and will monitor the self-repair process, to indicate whether there is a need for human intervention for inspection and/or repair.

This work was done by Erik Brandon of Caltech, George Studor of NASA Johnson Space Center, David Banks and Mark Curry of Boeing Phantom Works, Robert Broccato of Sandia National Laboratories, Tom Jackson of Penn State University, Kevin Champaigne of Invocon, Stan Woodard of NASA Langley Research Center, and Nancy Sottos of the University of Illinois at Urbana-Champaign for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov *. NPO-44519*