



Large-area, solar panel testing using LED solar simulation for 3J, 4J, 5J and 6J cell technologies

Space Power Workshop
Angstrom Designs
Casey Hare
April 27, 2022





Agenda

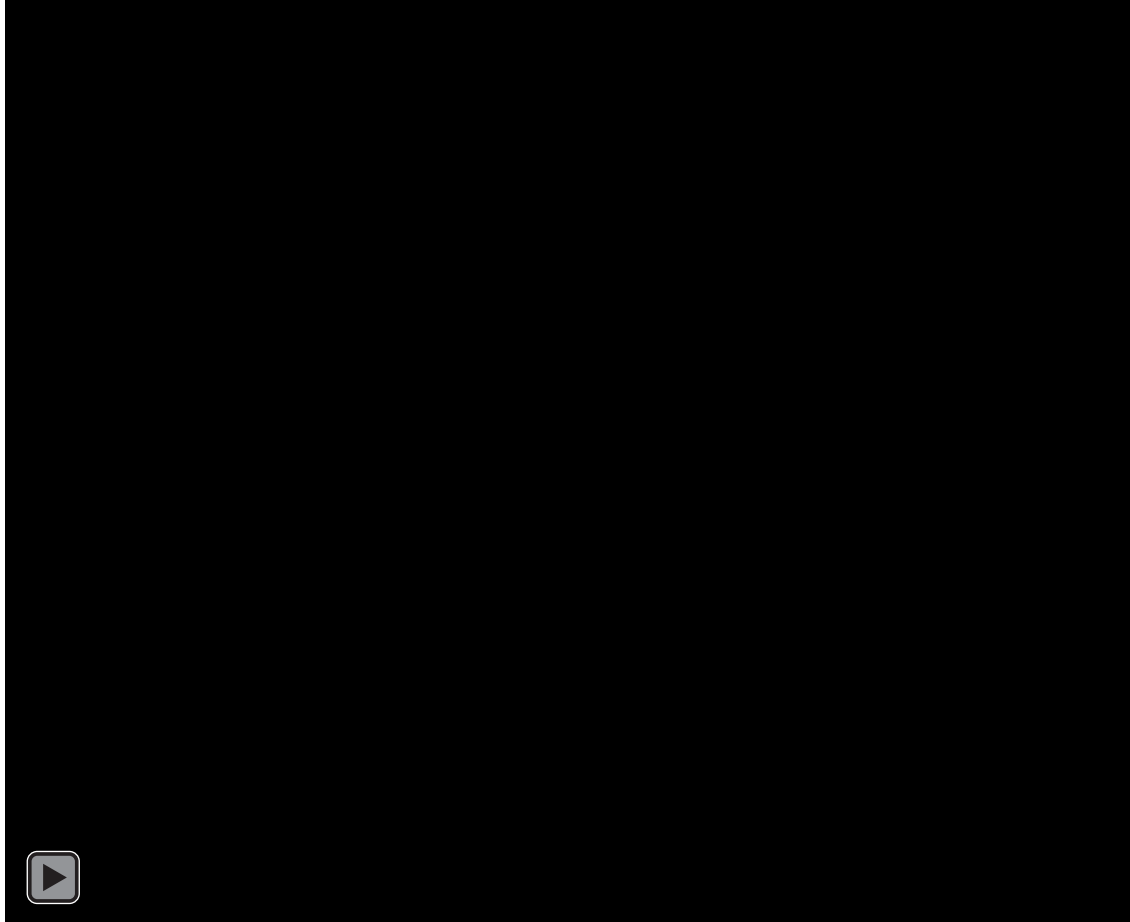
- Advances in Large-Area Beam Calibration
 - How LED Beam Calibration Works
 - Large-Area Beam Calibration
 - pLEDss DUT Zone Calibration Results
- Current Development
 - 6J Light Source Selection
 - Successful Transition to LED Module Manufacturing
 - Re-Implementation of pLEDss Calibrations
 - LED Solar Simulation Advantages
 - pLEDss vs. LAPSS vs. Dark IV
- Large-Area pLEDss
 - 5J – 0.39m x 1.88m – Pulsed Only Dolly Tester
 - 5J – 1.69m x 1.45m – Continuous/ Pulsed Panel Tester
 - 5J – 2.86m x 1.45m – Pulsed Only Panel Tester
 - NASA PPE Design Proposal
 - Other Large-Area Frame concepts
- Future Capabilities
 - Potential pLEDss Applications





How LED Beam Calibration Works

- pLEDss = “programmable LED solar simulator”
- AM0 test of panels gives confidence before launch
- We call each junction location of each DUT cell a “zone.”
 - So a 10-cell string of 5J cells has 50 zones
- The LEDs visit each zone at least once during beam calibration
- This is easy to see on this small-area, table-top pLEDss



Near-field illumination using LEDs for solar panel test:

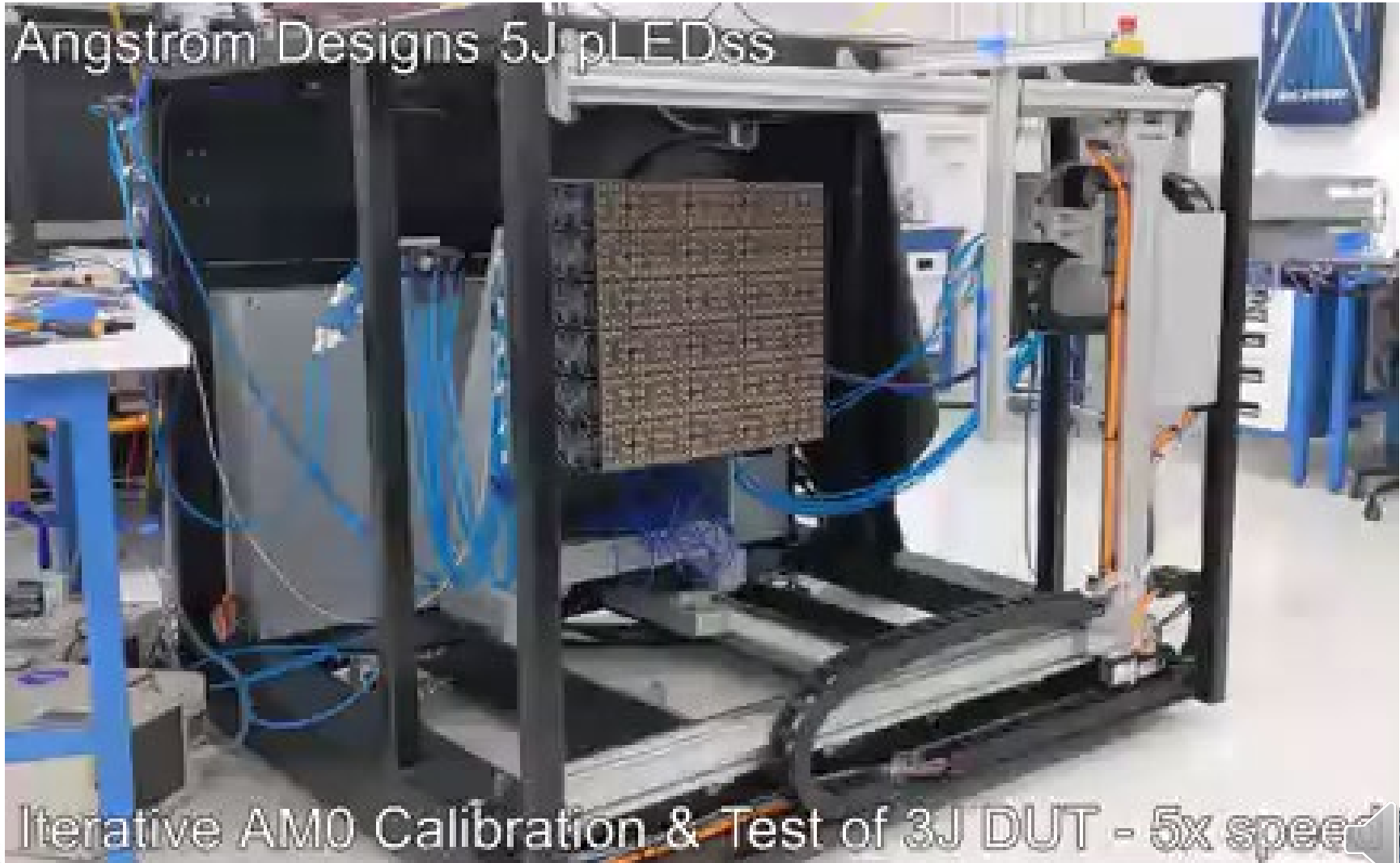
- Calibrate AM0 beam:
 - Visit each isotype where a DUT cell will be tested in the beam
 - Update beam output, if needed, and repeat isotype tests
- Measure DUTs
- Check AM0 beam calibration



Large-Area Beam Calibration

5J Continuous Coupon Tester

- 5J – 0.53m x 0.52m pLEDss installed in the field
- Continuous or pulsed capable
- Isotypes are on the motorized “calibration plate,” zone measurements are unchanged

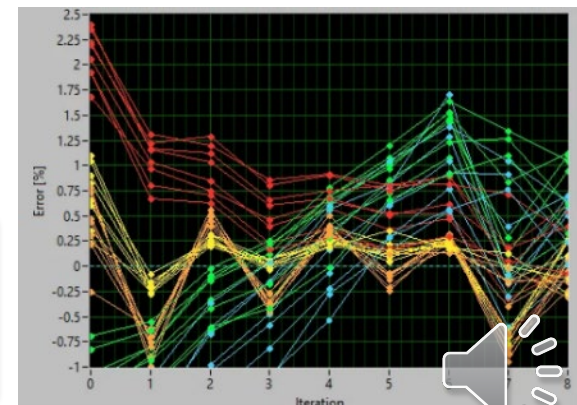
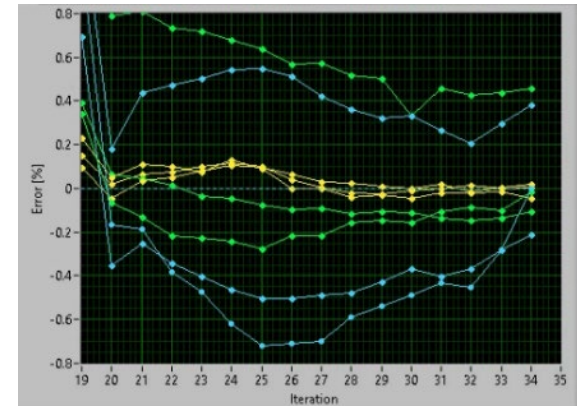
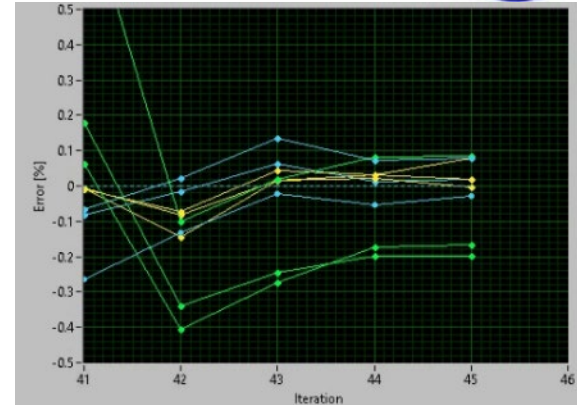




pLEDss DUT Zone Calibration Results

- ASTM industry standard is $\pm 2\%$
- pLEDss zone errors:
 - Single cell = $\pm 0.4\%$ (from years ago)
 - Multi-cell = $\pm 0.5\%$
 - New calibration routines from March
 - Consistent results for 3J cells (6, 9, 24 zones) and 5J cells (10, 15, 40 zones)
 - Customer tests of 60x 5J cells (300 zones) is pending, with comparable results expected

pLEDss is 4x better than the standard for large panel tests





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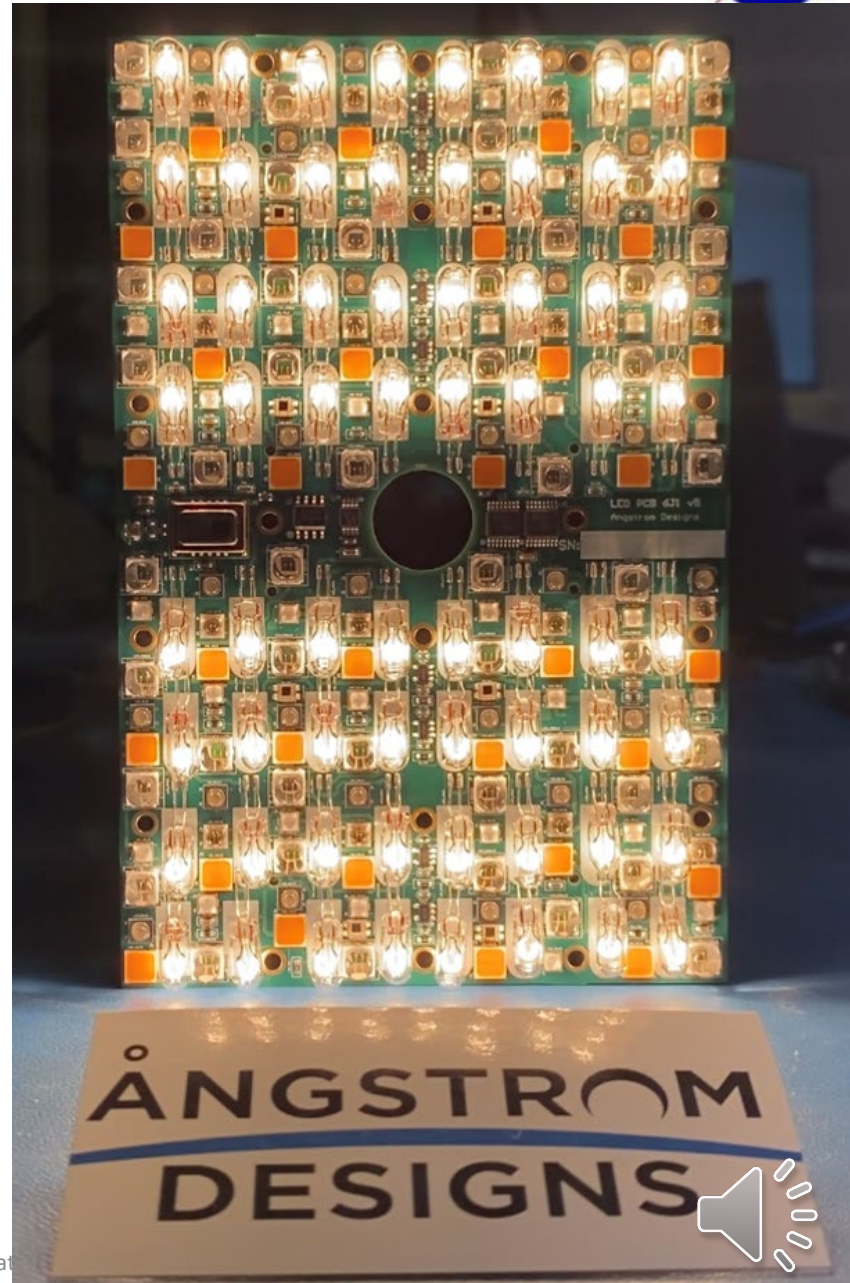
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6J Light Source Selection

- Recently completed a trade study to select a light source to enable 6J test capability
- Initial prototype testing is very promising
- Working toward integrating this source into our manufacturing flow

Future-proof, with 6J capability





Successful Transition to LED Module Manufacturing

- pLEDss module is in manufacturing
- LED Module manufacturing is underway:
 - From 2013 – 2019 we made less than 50 LED modules
 - Over 270 modules successfully manufactured since 2020
 - 240 more in manufacturing now

Manufacturing/ Covid
Issues Resolved





Re-Implementation of pLEDss Calibrations

Capability	pLEDss 2019	pLEDss 2021	
Single cell, continuous Isc match	±0.40%	±0.25%	
Light Field Generation Time	Manual: 2hrs-2days	Auto: 10sec-2min	
Initial Multi-Cell, Pulsed Isc match	±2%	> ±5%*	*Currently updating
Iterative Multi-Cell, Pulsed Isc match	±0.6 - ±1.2%	±0.5%	
Continuous Temporal Stability	0.09%	**	**Need to remeasure
Pulsed Temporal Stability	1%	**	**Need to remeasure

- Gen2019 LED modules surpassed industry metrics
- Gen2021 modules give better performance than Gen2019
- Confidence is very high that Gen2021 will surpass industry metrics by even more
 - Uncalibrated LED modules have larger error for tests with more cells and junctions. Calibrated LED modules do not.

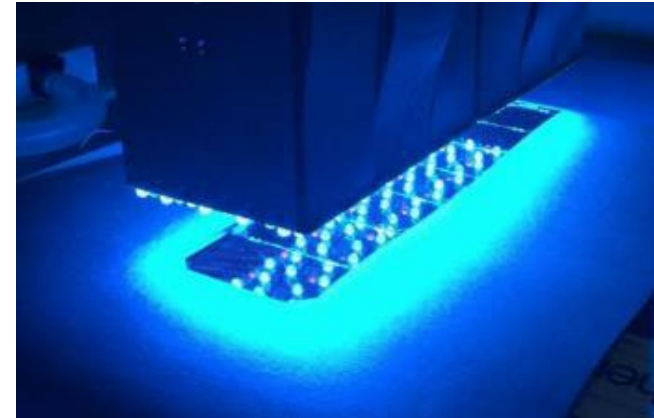
Gen2021 LED Modules continue to improve on previous performance





LED Solar Simulation Advantages

- Scalable to large areas
 - Add LED modules to increase test area
- Angstrom Designs has built 3, 4, 5 and 6 junction LED modules
 - Direct path to 7J+ cell test capability
- Excellent spectral adjustability, uniformity & stability
 - Automated measurement of light field: Isotype Isc of each junction of each cell
- Continuous or pulsed operation
 - Long pulses can test wings on spacecraft
- Horizontal or vertical panel testing
 - Small cleanroom footprint
- Fully automated calibration and testing
 - Can be controlled by Manufacturing Computer
- Spatial and Spectral control:
 - Intentional over/under-bias of junctions
 - AM0, LILT, AM1.5, ...





pLEDss vs. LAPSS vs. Dark IV

Metric	pLEDss	LAPSS	Dark IV	Comments
4J, 5J and 6J capable	Yes	No	Yes	
Accuracy	±0.5%	>= ±2%	???	
Cleanroom footprint	Small	Large	None	
Circuit-level test	Yes	Yes	No	
Ambient sensitivity	Low	Low	High	Temp and light affect Dark IV
Detects all defects	Yes	Yes	No	Except small cracks for all
Extra test connector	No	No	Yes	
Calibration measured	Yes	No	No	
Flight-like current density	Yes	Yes	No	
Automation	Full	Manual	Full	
Decays with area	Cost	Uniformity	None	
EOL biasing	Yes	Yes	No	
Test as you fly	Yes	Yes	No	

- Dark IV can not detect contamination defects nor some types of damaged junctions





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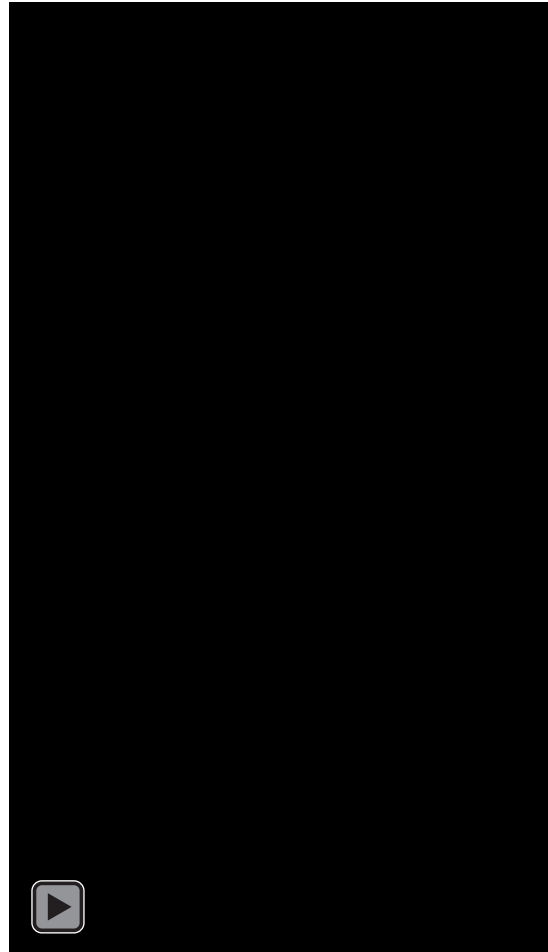
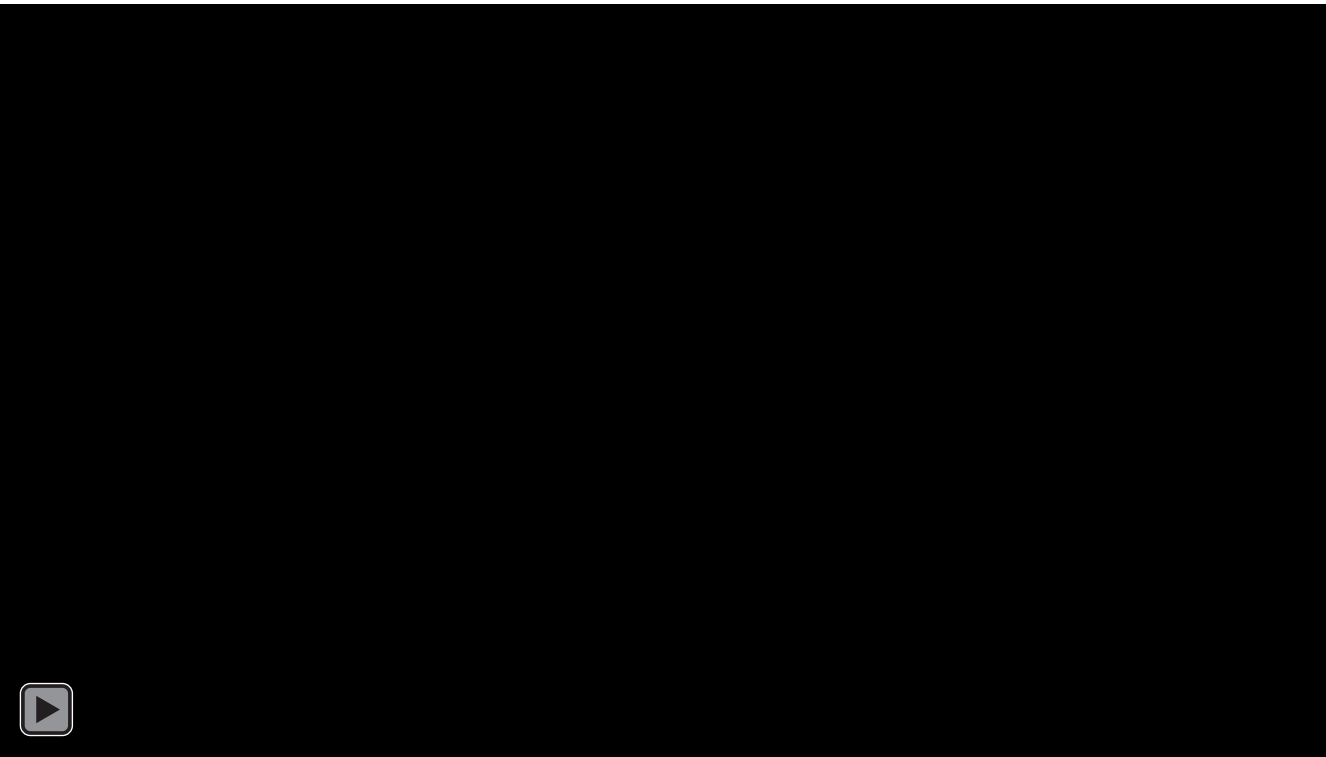
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5J – 0.39m x 1.88m – Pulsed Only

- Demonstration pLEDs for panels on dollies
- Installed in the field



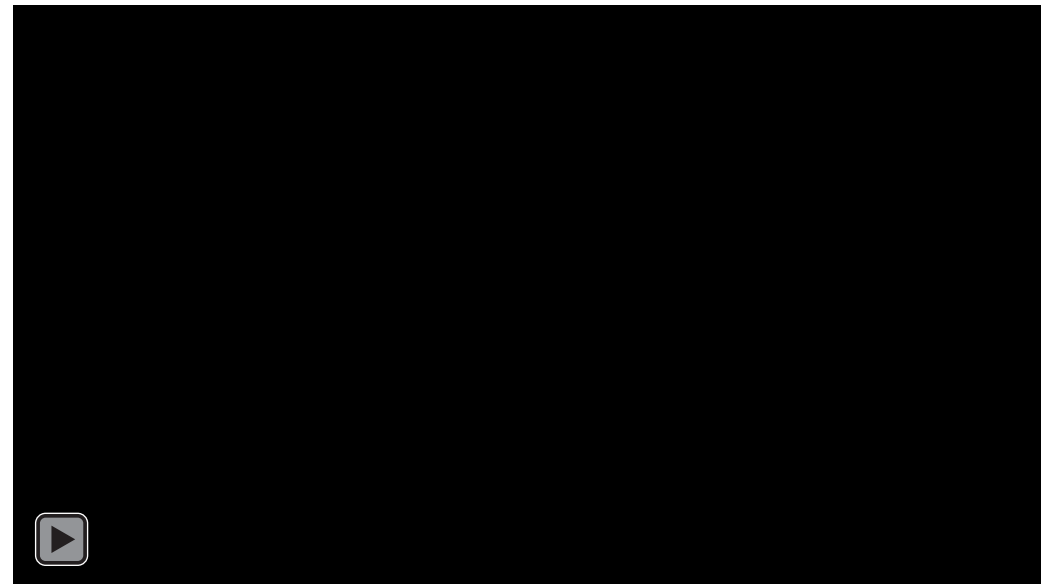
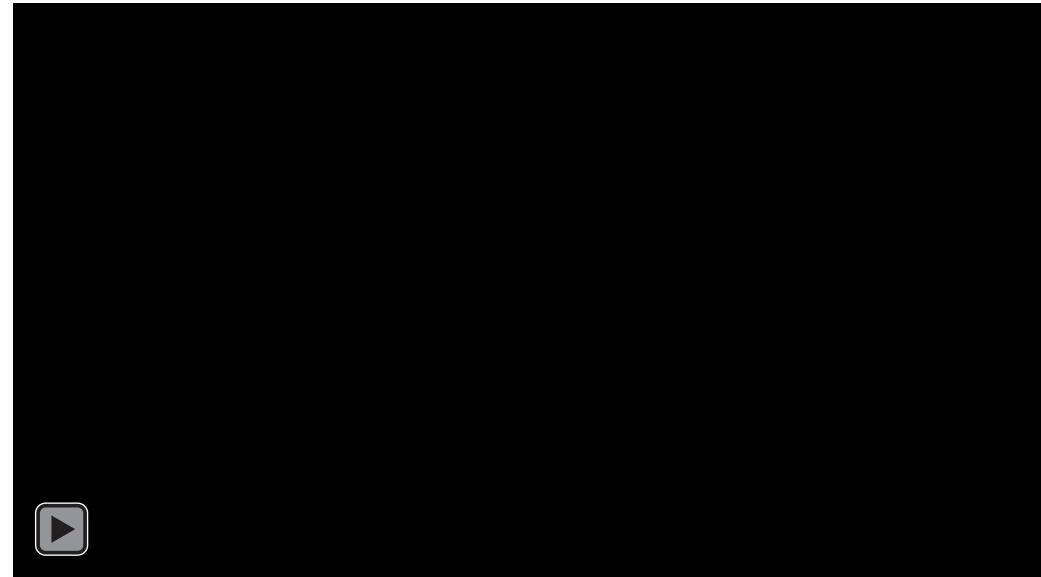
For Testing Panels on Dollies



5J – 1.69m x 1.45m – Continuous/ Pulsed



- The largest pLEDss system we've built
- 1.4 x 1.7m, continuous AM0 5J test capability
- Currently undergoing advanced, automated calibration



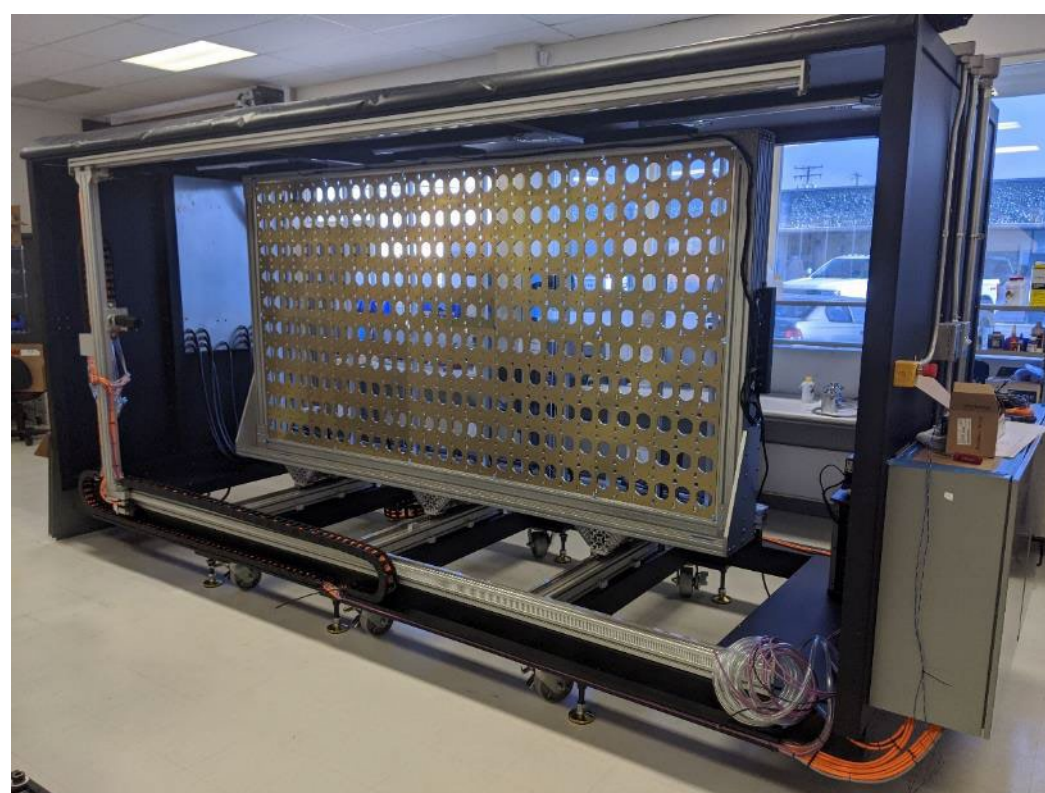
The Only Large-Area,
Continuous, 5J, AM0 Tester





5J – 2.86m x 1.45m – Pulsed Only

- Frame Build complete
 - Frame can hold up to 30 x 10 LED modules
 - Modules can be moved to match panel shape
 - All pLEDss frames are custom, but leverage common design heritage from previous frames
- 240x 5J LED modules are in manufacturing



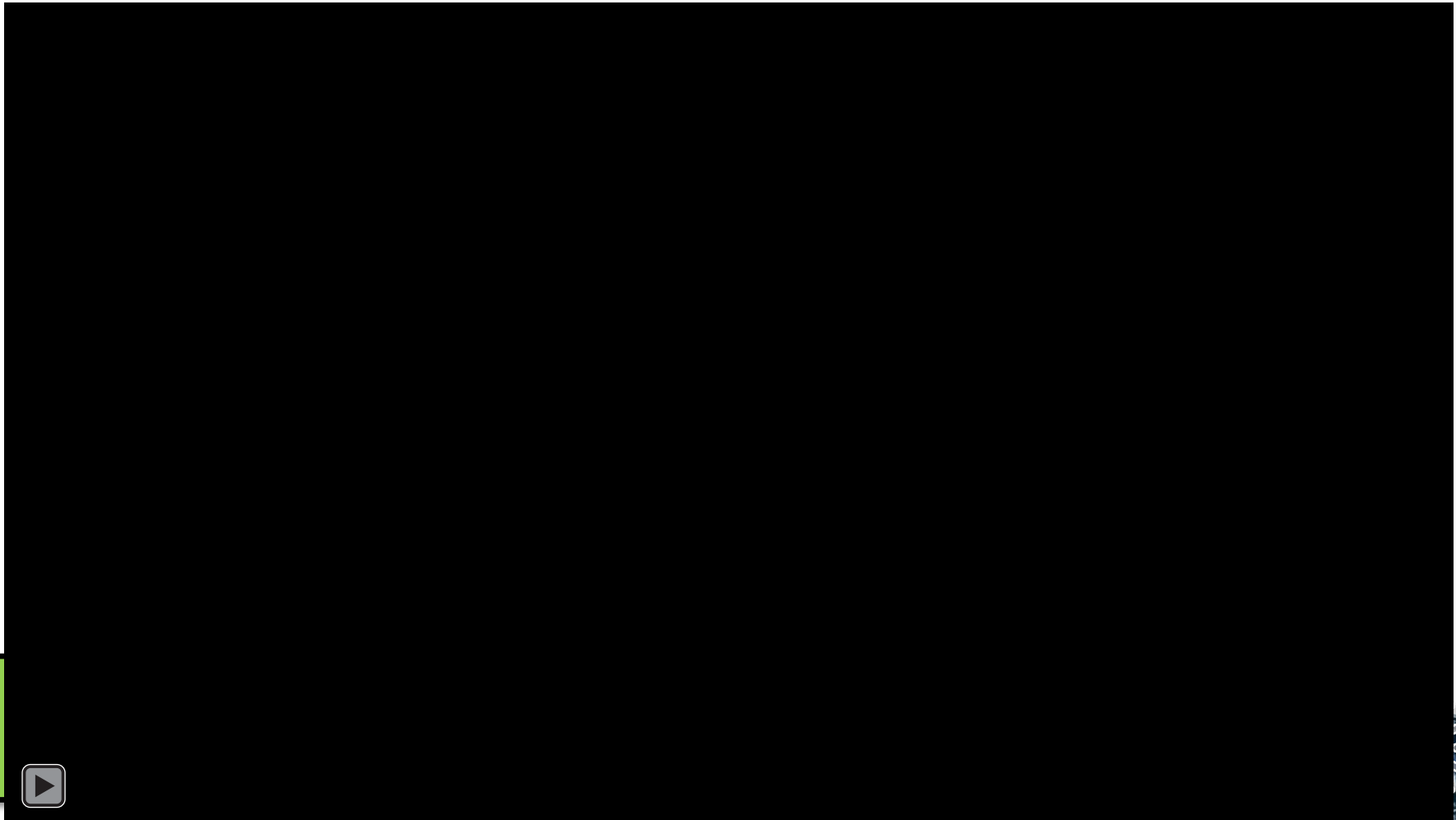
The Largest Frame Yet.





NASA PPE Design Proposal

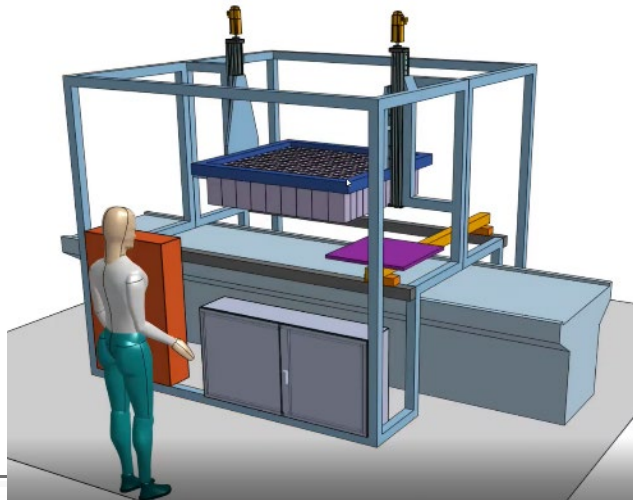
- Power Propulsion Element (PPE) Proposal:
 - 240 5J pLEDss modules
 - A new, huge gantry frame for calibration and test



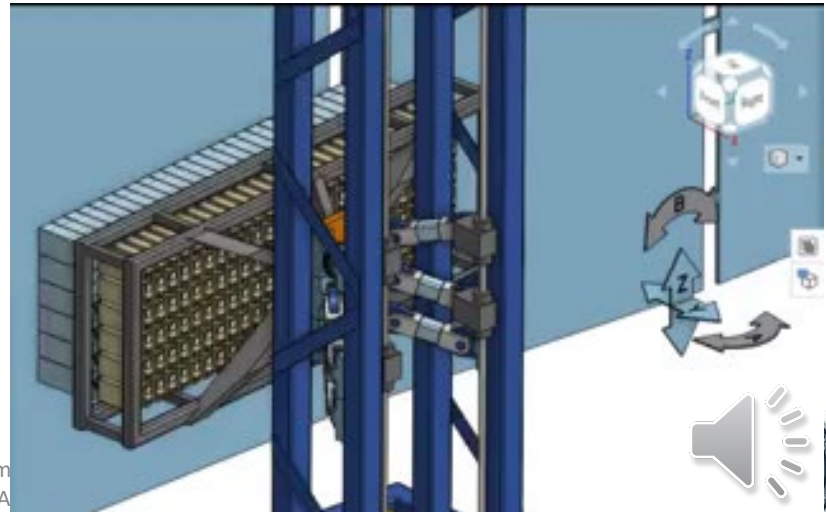
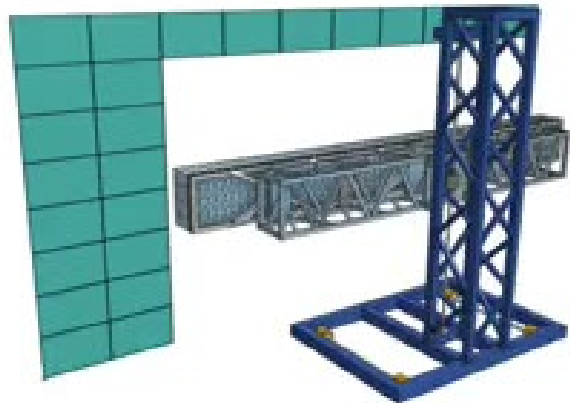


Other Large-Area Frame concepts

- All frames are semi-custom, so many other configurations are possible.
 - Some concepts so far:



An Automation Frame for Many Different Needs



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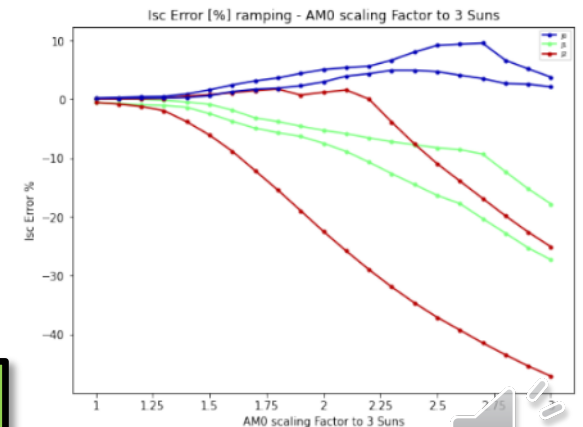
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Potential pLEDss Applications

- pLEDss modules have a hole in the center of the LED PCB for a small visible or infrared camera, enabling:
 - Visible and IR inspection
 - Supported by machine vision/ pattern recognition
 - Functional and electrical testing
 - Electroluminescence and Photoluminescence imaging
 - Thermography: adhesive bond QA
- Spectral and spatial control enable many applications
- A platform for automated testing
 - TCP interface allows remote control
 - Integration into fully-automated manufacturing lines
- Advanced simulation for maximum utility: low-intensity, high-intensity, ...



pLEDss is a Highly Flexible Platform



Thank you

- pLEDss solar simulator:
 - GRC for preliminary SBIR funding and on-going tech expertise
 - SSC for transition to manufacturing funding
 - AFRL for 6J light source trade study SBIR
 - Northrop Grumman, Aerospace, JPL and Solar Junction for commercial support
 - Industry experts for their feedback and guidance: Jeremiah McNatt, Matt Myers, Alex Haas, Taner Bilir, Ding Ding, Phil Jenkins, Dave Wilt, Don Walker, Colin Mann, Rob Walters, Christopher Kerestes, Paul Sharps, Nathaniel Miller, Kody Audette-Ingbretson, Albert Perry III, Andreea Boca, Mike Eskenazi, Jeff Manson, Simone Missirian, ...
- Thank you for your attention
- Any Questions?

