

PACT Module Design Acceptance Criteria (Industry)

Version 2

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Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Executive Summary

The mission of the PACT center is to develop performance and reliability testing protocols and measure outdoor performance of perovskite photovoltaic modules. PACT seeks partnerships with industry partners that are producing modules (mini and full-sized) for testing purposes. To ensure both safety and high-quality samples PACT publishes acceptance criteria to define the minimum characteristics of modules the center will accept for testing. These criteria help to ensure we are accepting technologies that are compatible with our technical facilities and testing equipment and can transition to large scale commercial manufacturing.

This module design acceptance criteria document is for industry partners and is different from the acceptance criteria for research partners (academia, national laboratories) partners.

Updates to the criteria are expected over the lifetime of the PACT center. When changes are made a new version will be published. Specific changes to the document will be outlined below.

Version Updates

Version 1.0 – Initial release

Version 2.0 – Simplified requirements

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1. INTRODUCTION

For the PACT center to both develop testing protocols and provide service to the metal halide perovskite (MHP) PV community, PACT seeks modules (mini and full-sized) for testing purposes. To ensure both safety and high-quality samples PACT publishes acceptance criteria to define the minimum design characteristics of modules the center will accept for testing. These criteria help to ensure we are accepting technologies that are compatible with our technical facilities and testing equipment and can transition to large scale commercial manufacturing.

PACT may not accept all modules, even if they meet all the acceptance criteria due to limited resources and/or too many of a similar type, design, construction, or composition. In the event capacity limits the modules that can be accepted by the center, PACT leadership will review available modules and prioritize based on the programs needs and deliverables. We fully anticipate that these acceptance criteria will change over time in response to advances in the technology and testing capacity limitations of the PACT center.

2. DEFINITIONS

- **Module** - weatherproof package containing multiple, interconnected solar cells that can be electrically connected to an external load
- **Batch** - group of samples fabricated from identical materials using identical processes
- **MHP** – Metal Halide Perovskite
- **Industry samples** – Modules provided by industry partners. All PACT testing for industry samples shall be governed by a **PACT Test Plan** to be drafted prior to sending any samples. The test plan will be developed in meetings between each industry partner and PACT.

3. ARCHITECTURE AND TYPE

- Samples shall be modules with a junction box connecting the module to electrical leads/wires.
- Solar cells in samples shall contain a MHP absorber layer.

Note: There is no requirement as to number of absorbers, number of junctions per cell, or bifaciality. However, submission of bifacial modules shall be arranged in advance because they may require special testing and mounting considerations.

4. CHEMICAL COMPOSITION

Please provide the specific chemical composition of the module upon submittal to the PACT center.

Note: at this stage of the program there is no restriction, limitation, or guidelines for module chemical composition.

5. BATCHES

- Samples shall be delivered in groups of at least three samples from the same batch for each test that will be performed by the PACT center. It is encouraged, but not required that at least three more samples be delivered from the same batch for development and validation of preconditioning protocols for measuring performance.
- Samples that have been subjected to accelerated testing prior to arriving at PACT shall not be counted in the sample totals per batch.

6. MECHANICAL REQUIREMENTS

6.1. Shape, Size, and Labeling

Samples shall be rectangular.

- Additional requirements for industrial samples:
 - Samples shall have a minimum width of 148 mm, excluding the junction box
 - Samples shall have a minimum length of 148 mm.
 - Detailed descriptions of physical dimensions shall be shared with the PACT prior to sending samples.
 - Labels indicating sample IDs and other information shall be placed on the rear side of the modules. PACT will add labels with PACT IDs and other tracking information. It is important that all samples are labeled before sending to PACT so that test results can be compared with tests run by the manufacturer.

6.2. Designated area

- The designated area for use in estimating efficiency will be defined by a single rectangle that encompasses active cells in the module.
- PACT may apply an aperture during testing to ensure that efficiency measurements do not include extraneous sources of light (e.g., from the glass edges).
- We do not have a strict requirement of a minimum acceptable “active” area but will prioritize devices with designated areas greater than 100 cm².

6.3. Junction box

- Requirements for industrial samples:
 - Modules shall ideally pass a wet leakage current test (IEC 61215-2 MQT 15). This test subjects the sample to at least 500V of potential while the module is shorted and submerged in a water bath to test the insulation of the package and junction box.
 - Samples using identical packaging designs that have been shown to pass a wet leakage test may be tested at PACT without passing the test.

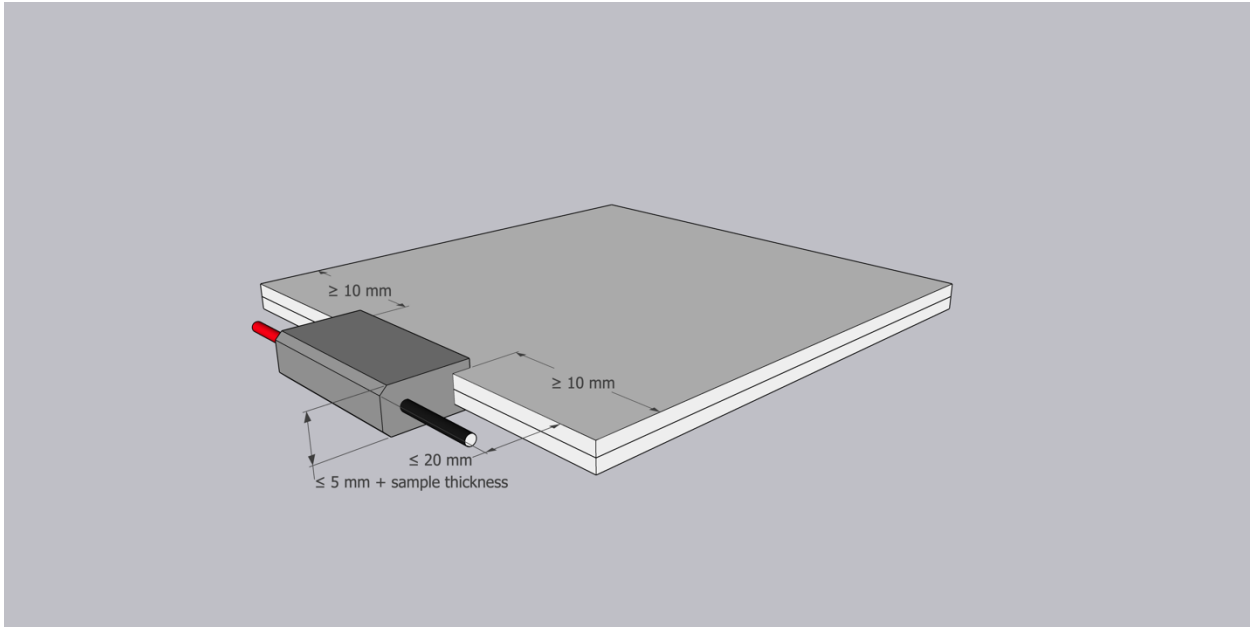


Figure 1. Example of a side-mounted junction box configuration showing one possible wiring configuration.

6.4. Wires

Insulated copper wires shall be included to connect samples to an external load.

- Conductors shall be suitable for safely carrying the maximum current produced by the module.
- Insulation shall be suitable for safely carrying the maximum voltage produced by the module.
- Wire shall be listed and labeled for outdoor PV use.
- Wire shall be no smaller than 20 AWG and no larger than 14 AWG.
- Wire length from the module shall be long enough to allow flexibility for installation and testing. PACT recommends wire length of 3m, if possible. Length shall be specified and agreed upon in the **PACT Test Plan**.
- PACT has standardized on the following connector type:

6.5. Rigidity

- Samples shall be rigid enough that they can be safely mounted by attaching only to the frame or edge of the module.
- Flexible modules shall be delivered to PACT mounted on a rigid substrate to allow mounting.
 - If temperature monitoring is important for testing of flexible modules, at least two thermocouples shall be attached to the rear surface of the module prior to mounting to rigid substrate. These details shall be included and agreed upon in the **PACT Test Plan**.
- Vendor to provide module mounting solution.

7. ELECTRICAL REQUIREMENTS

- Aperture efficiency shall generally be $\geq 12\%$ (single junction) or $\geq 16\%$ (Si-perovskite tandem) at standard test conditions. Lower efficiency modules may be considered as long as there is a clear path to higher efficiency.
- Open-circuit voltage shall be ≤ 60 V at standard test conditions.
- Short-circuit current shall be ≤ 15 A at standard test conditions.
- No exposed parts shall be electrically connected to the internal module circuit, other than the distal ends of wires.

- Electrical characteristics (Voc, Isc, Vmp, Imp, etc.) of industrial samples shall be documented in the **PACT Test Plan** to ensure that PACT has the hardware to monitor the performance of the module.

8. PRELIMINARY TESTING

- Three samples from the same batch as those submitted shall pass either (a) 100 hours of ISOS-L2¹ or (b) 100 hours of ISOS-D2² and 100 hours of ISOS-V1³.
- Samples shall pass a home lead swipe test⁴ to confirm the exterior is not a health hazards for ordinary (non-gloved) handling. Pass is defined as “no lead detected” on the swab and photo documented and submitted per section 8.

9. DOCUMENTATION

- Documentation shall be provided in electronic form, including:
 - Evidence that the preceding electrical requirements have been met on every submitted sample.
 - Sufficient information to link electrical measurements to a specific sample
 - Note: This requirement can be met by assigning a unique identifier to each module and attaching an identifying label to rear side of module.
 - Evidence that preliminary testing requirements (section 8) have been met on samples from the same batch
 - ISOS-recommended sample preparation information
- Samples without documentation cannot be accepted

10. OTHER INFORMATION THAT MAY BE REQUIRED FOR SOME SERVICES (FOLLOWING APPROVED NDA)

- Please provide brief bios of key team members including previous experience, current role and responsibilities and education.
- Is any intellectual property associated with the module or is any intellectual property being applied for?
- Please provide a full bill of materials (BOM). The BOM should include the part name, part number or code, and part count.
- Please provide description or documentation of manufacturing processes being used to produce the module.
- If the module is being manufactured please provide current monthly capacity.

¹ Khenkin et al., 2020 – ISOS-L2 refers to light soaking testing that measures how the module tolerates exposure to continuous light at typical operating temperatures (e.g., 65°C and 85°C). Power rating is compared before and after light soaking at 65°C and 85°C for 100 hours.

² Khenkin et al., 2020 – ISOS-D2 refers to dark storage testing that measures how the module tolerates exposure to the atmosphere and elevated temperatures while being stored in the dark. Power rating is compared before and after dark storage at 65°C and 85°C for 100 hours.

³ Khenkin et al., 2020 – ISOS-V1 refers to electrical bias testing in the dark that measures how the module tolerates this stress. Power rating is compared before and after exposure to electrical bias at ambient temperature.

⁴ Example home lead swipe test can be purchased online.

https://www.amazon.com/dp/B07NBH7KJJ/ref=cm_sw_r_tw_dp_3MJ36572DD80PM6677J0

11. APPLICATION TEMPLATE

Companies interested in testing their perovskite PV modules at the PACT center should fill out the following form and return to Kailey Wulfert (kwulfer@sandia.gov) for processing. After review, PACT will contact the company to discuss next steps.

Company Information

Company Name:

Company Address:

Company Website:

Technical point of contact:

Name:

Title:

Email:

Phone Number:

NDA/MTA Business Point of Contact (if different than technical point of contact)

Name:

Title:

Email:

Phone number:

Which testing services are you interested in? (Rank in order of preference, 1=highest priority)

Testing Services	1	2	3	4	5	6
Outdoor testing in Albuquerque* with energy yield monitoring						
Multiple climate outdoor testing with energy yield monitoring						
Indoor performance testing**						
Accelerated ageing test						
Environmental toxicity testing (leaching, fire)						
Postmortem (destructive vs. nondestructive)						

*Note: PACT has funding to test industry modules in Albuquerque at Sandia National Laboratories and CFV Labs.

We plan to offer testing sites in other climates in future years.

** Note: PACT indoor testing services include development of module preconditioning and rapid testing methods (e.g., flash). Companies should contact NREL if they want modules tested for evaluation against the Champion PV Module Efficiency Chart.

Additional comments:

Module Technology

Cell Technology

Please list/describe the materials used for the following:

Substrate material:

Contact:

Transport:

Absorber:

Transport:

Contact:

Module Specifications

Materials used:

Top cover material:

Back cover material:

Encapsulant material:

Edge seal material:

Junction box:

Wires/ribbons:

Outer dimensions (Length, width, thickness) – specify units:

Total area:

Active area:

Geographic fill factor:

Number of cells in series:

Number of strings in parallel:

Expected or Measured STC module performance?:

Isc (A):

Voc (V):

Pmp (W):

Fill Factor:

Module Samples

Number of modules that can be provided to PACT:

Date modules can be available:

Describe module recurring delivery schedule (if applicable):

Module Testing (prior to PACT)

What testing has been completed on the current module design? Note: PACT may be able to help companies obtain such preliminary testing.

- Performance characterization (e.g., STC IV curves, MPPT, etc.)?
Yes
No
Unsure
- Wet leakage current test (IEC 61215-2 MQT 15)?
Yes
No
Unsure
- 100 hours of ISOS-L2?
Yes
No
Unsure
- 100 hours of ISOS-D2?
Yes
No
Unsure
- 100 hours of ISOS-V1?
Yes
No
Unsure
- Lead wipe test?
Yes
No
Unsure
- Other:

Briefly describe your commercialization plan. What markets are you targeting? What is your plan and schedule for manufacturing? How do you plan to scale up production and module size?

PACT

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