IceCube Upgrade mDOM Final Design Review (WBS 1.3.1)

Final Report, but not yet presented to the IceCube Upgrade Tech Board

11-13 April 2022, DESY-Zeuthen & Remote

Charge

The panel is charged with reviewing the IceCube Upgrade mDOM design status at the level of a final design review. The expectation is that the prototypes have undergone a successful design verification, that the requirements are met by the as-built modules, that the plan moving forward into a pre-production path of forty modules is well understood and acceptable, and that the processes and tests are sufficiently documented. We aim here to call out any outstanding issues in a constructive manner commensurate with both minimizing project risk and also keeping to good schedule progress. Recommendations will be made through a written report.

Agenda

The agenda is in this spreadsheet.

Review Panel

M. DuVernois (chair), A. Hallgren, A. Ishihara, P. Sandstrom, D. Tosi, Ch. Wendt

Useful Links

- Design Verification Tracker
- mDOM CMD, mDOM DSN, mDOM ERD, mDOM IDD, mDOM FAT DSN
- Material for the Final Design Review
- Preliminary Design Review (Mechanics)
  Panel: Michael DuVernois (chair, UW-WIPAC), Aya Ishihara (Chiba), Allan Hallgren (Uppsala), Lee Greenler (UW-PSL), Christopher Ng (MSU)
- Preliminary Design Review (Electronics)
  Panel: Michael DuVernois (chair, UW-WIPAC), Andrew Laundrie (UW-PSL), Brian Ferguson (MSU), Matthias Kleifges (KIT)
- High-Voltage Subsystem Informal Review

Summary

The mDOM design, one of the two principle optical sensor modules for the IceCube Upgrade, passes its final design review. Tests and analysis of prototype MDOMs show that the final design fulfills the design requirements in a robust way. The mDOM team is to be congratulated for their excellent work, including a significant amount of work undertaken during the less-than-favorable conditions of the pandemic.

The panel has a set of recommendations, enumerated below, which reflect a few questions or comments related to the design, and some additional questions or comments related to the upcoming production processes. We do not see any of these as critical design issues, but in a couple of cases we do note suggested follow ups.

Recommendations (in no special order)

1. **Storing useful calibration information.** Production calibration data has always been intended to be sent to the database, and that seems to be taking place. Let's also make sure we save any and all useful information on the test stands, procedures, input signals, and data analysis techniques such that people years from now doing calibration or characterization work with the *in situ* Upgrade optical modules will have an easier time understanding the measurements recorded during construction. This suggestion arose a couple of different times during the presentations. In general, there is little disadvantage of storing additional data.
2. **Copying the DESY installation facility to MSU.** This seems to be a significant task, and we applaud the early work on it. Some differences between the setups are expected, but a goal should be to make the modules indistinguishable in production for the two sites.
3. **Glue specifications for the reflector rings.** Please add documentation on the glue used to the design library. Is this the same as the glue for the flasher LED and camera windows?
4. **Shin Etsu gel shelf life.** This isn't viewed as a large concern, but it might be nice if a more authoritative statement could be obtained from the vendor of the usability of the gel after storage. Is this information available from the vendor?
5. **mDOM mainboard electronics parts.** Could you comment on the availability of parts other than the Xilinx FPGA? Are there other parts with uncertain availability? A plan to accelerate purchases of these parts? A backup plan to switch out these parts?
6. **Non-Conforming Materials (NCM) handling.** We should utilize the NCM reporting and processes during production. There were a couple of examples shown of problems with parts during production (cameras returned to the vendor, flasher boards with misaligned connectors, etc.) which might benefit from analysis and documentation. We should encourage use of the NCM process as needed.
7. **Differences between DVT and Final Versions.** Should have a write-up for each change between the DVT test articles and the final production versions, along with comments on what testing should be recreated for the definitive versions. Also include any open issues with a plan to close those issues. For each change compared to "DVT," the list should explain some details of the change, whether the effect will be re-tested (or already was), and if it's not re-tested then a sentence (or few) "analysis" how it's determined that requirements are still met.
8. **Vibration and Shock Testing**. We understand this will be done with the final version of the mDOMs, and that is encouraged. A plan for the final attachments of all of the cables is needed, will they be glued? Other anti-vibration connections? The cables must never be disconnected by pulling on the cable. The cabling & connector plan to be presented in follow-up discussions should include the details of the cable routing, especially those in the central region between two half-modules being assembled together. The connectors and cables are expected to be successful and robust, but this is a point of vulnerability during integration and the process for checking and recording that each connector is fully mated should be written down and followed at each integration site. That might include a magnified optical inspection of key features on each connector when first mated and possibly again later if still visible after further integration steps. Quality control of the cables themselves was not mentioned but is similarly important (*i.e.*, the connectorization).

9. **Camera connection gluing.** We saw a video (https://drive.google.com/file/d/1EW4GHElv31U2DvxTCXfVnNTXtJTDQX9t/view) with some sort of silicone adhesive added to the pins of a camera board connector. This procedure we do not believe has been discussed elsewhere, and seems very irregular. No one involved with the review has heard of such a process and there are many concerns. Though electronics-safe “neutral-curing” RTVs do exist, in general “acetoxy-cure” RTVs attack copper and potentially other metals. Adhesives applied to the pins here will spread randomly within the spring-contacts. See more details in Appendix A.
10. **Requirements testing:**
    a. The FR1 test (recording SPE events) was presented using SPEs captured with a trigger connected to the light flash, i.e., without using the discriminator trigger. It would be good to update the test results using discriminator-triggered SPEs, which would demonstrate that rare fluctuation of random electronic noise is not competing with true SPE detection/recording.
    b. The FR4 test (gain calibration using flasher LEDs) was done with untaped modules, resulting in significantly more light reflecting back onto the PMTs compared to the expected in-ice situation. In discussion, it was pointed out that the same demonstration would have been even easier with taped modules, so it's not necessary to do that also. This explanation was given and accepted in the verbal Q&A but it should also be written out for the FR4 result documentation.
    c. Module-level spe timing resolution, PR1: As presented, this measurement was done at MPE level. Because the SPE level time spread is larger, the results should be updated in the reference materials when those measurements are ready.
11. **Harness load testing.** Is the requirement to test all harnesses well motivated? Also, the MSU test stand for the load testing raised safety questions. Could the safety of that system be discussed with the project safety manager, Mike Zernick?
12. **Long term test items**. The mDOM team is encouraged to place one or more integrated mDOMs into long-term operation at low temperatures. A long term plan for the calibration PMTs, and any “reference” mDOMs, should be identified.
13. **PMT sizing.** The nominal tolerances of relative diameter between PMT necks and the support structure openings seem to allow for variations of several mm. It's likely that both the structure and the PMTs will be much more consistent than that. Beyond a certain level of variation, the o-ring sealing method would not work without taking extra measures (e.g., assortment of o-ring thicknesses available depending on each PMT position). The threshold for such problems seems not currently documented, but is likely to be less than the several mm variance, mentioned in one presentation. Suggest to plan that after structures and PMTs are in hand, the distribution of sizes will be documented to justify keeping a common o-ring thickness, or leading to appropriate measures to ensure all cases will be properly sealed.
14. **LED assembly.** The flasher LED emission axis accuracy has been partially evaluated against the requirement and some tests will still be done on that. It seems the tests apply to the LED and flasher board assembly before integration. How is the wire bend angle prevented from changing during assembly into the support structure, and how is this to be verified during production?
15. **Baseline fluctuations.** In the testing of PMT assemblies, it was suggested to add a test for fluctuations of the baseline during HV operation, as might be expected from defects in the noise filtering components on a base circuit board. If baseline fluctuations were to

approach the 0.1 or 0.2 PE level, it would affect the charge precision as well as cleanliness of single photon triggering and detection.

16. **mDOM Documentation**. Creation of an IDD for the mDOM may be useful. There is presently no content in mDOM FAT DSN, which would be a good place to store links, photos and block diagrams of the mDOM FAT setup. mDOM FAT (DSN or PCR) can be a line item in mDOM CMD. Consider adding hyperlinks to the CMD as others have done to make this spreadsheet a place where all mDOM documents can be reached.

Conclusions

The mDOM design is in excellent condition, and ready to enter into test batch production. This has been a long development effort carried out by a number of institutions during a difficult time due to the pandemic. The full team is to be congratulated for their hard work, dedication, and superb results. The recommendations above are offered in the spirit of collaboration and assistance. Most were discussed at least somewhat during the review.

Thanks again to all review participants!

Status checklist from the mDOM CMD

	Filename= mDOM CMD								
sorting			Design Status	Conceptual Design (C)		Preliminary Design (P)		Final (F)	
CMD ID	ITEM NAME	DESCRIPTION	(C,P,F)	Requirements Baselined	Block Dia, Select Main Parts	Details, interfaces, BOM	Design Verified, Prod Docs	Prototype Verified	Procure, Production Plan
1	mDOM PMT	photomultiplier	F	X	X	X	X	X	X
2	mDOM Support Structure	3D-printed structure to fix PMTs, mainboard, calibration devices etc.	F	X	X	X	X	X	X
3	mDOM Reflectors	reflect photons onto PMT	F	X	X	X	X	X	X
4	mDOM Gel	optical gel	F	X	X	X	X	X	X
5	mDOM Pressure Vessel	pressure vessel	F	X	X	X	X	X	X
6	mDOM Harness	harness to mount module to MCA	F	X	X	X	X	X	X
7	mDOM Mainboard Assembly	MB + mDAB + ICM asssy. for readout of PMTs, signal processing, communication and power	F	X	X	X	X	X	X
8	mDOM HV System	system to generate high voltage for PMTs	F	X	X	X	X	X	X
9	Penetrator	feedthrough for power, comms and data	F	X	X	X	X	X	X
10	mDOM LED System		F	X	X	X	X	X	X
11	mDOM Camera System		F	X	X	X	X	X	X
12	Ice Comms Module (ICM)		F	X	X	X	X	X	X
13	mDOM Integration Hardware		F	X	X	X	N/A	X	N/A
14	mDOM Integration Procedure		F	X	X	X	N/A	X	N/A
15	mDOM Firmware		F	X	X	X	X	X	N/A
16	mDOM Software		F	X	X	X	X	X	N/A
17	mDOM Packaging		F	X	X	X	X	X	X

Appendix A: Additional comments and concerns on the gluing of connectors

My question is if this is a standard or in any way recommended procedure, approved and stamped as good?

Disconnecting seems nearly not possible, that may be OK. But is the connection long term guaranteed when having put the silicon on the pins?

Side remark on why I may be somewhat concerned.

I remember once when we had succeeded to combine RTV silicon rubber (emitting some acetic acid) with a sensitive drift chamber having CuBe wires. All wires went blue over night, chemist said it was a salt formed between the Cu and the acetic acid vapor,. We could luckily get it off with pure water....

So I worry a bit, but maybe better silicon, and gold plated pins help. Just wondering about the method. I assume we have it in all the cameras being installed. Maybe its a good way?

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I also looked at the video of someone applying silicone RTV directly to the header pins on a camera. I have never seen this done before, and found it somewhat alarming. I have a hard time believing this is a good thing to do because the material will be incorporated into the spring contacts (in a highly variable way). Unless there is some established industry practice that I am not aware of, adhesives should probably never be applied directly to header pins like this regardless of what type of adhesive is used.

Below are some other thoughts on this issue. Timo also suggested in the review that the ribbon cable retention issue would be discussed further in the HW call.

There are "neutral cure" RTV silicone adhesives that are specified for use on electronics (they don't smell like vinegar). But the other "acetoxy-cure" type will indeed attack copper and probably other metals and should never be used. Hot glue is sometimes used for retention of items to PCBs, but would likeley not be recommended here because of the danger in distorting the thermoplastics in the ribbon cable and Insulation-displacement connectors.

I believe that a "permanent" adhesive bond of ribbon cable connections (especially at the mainboard end) is likely unnecessary, and is something that should be avoided, especially during early stages of mDOM integration development.

There are likely ways to augment the retention/ejector latches on the ribbon cables on the mainboard end that would still allow the mDOM to be taken apart. I mentioned a small strip of Kapton tape across the tops of the IDC and ejector latches as one approach, but there may be others.

Without actually seeing the situation, it is hard to say, but I suspect that the ejector latches should probably not be discarded because of one instance of mechanical interference that could perhaps be avoided through different cable management during PV closure.

The approach of using headers without ejector latches to allow application of some additional (non-permanent) retention means (like tape or a *minimal* dab of RTV between the ribbon IDC connector and the PCB) may also be worth considering, but should be approached with caution.

If the ejector latches are not used, these fine-pitch ribbon cables should never be removed from their headers by pulling on the cable itself, and would require probably even more difficult access to take apart and to visually ensure that they are seated properly. The 3M ejector latches provide a good visual indicator of proper seating and otherwise represent a presumably proven and highly-engineered approach that may be hard to improve upon.