Electrical Design 1

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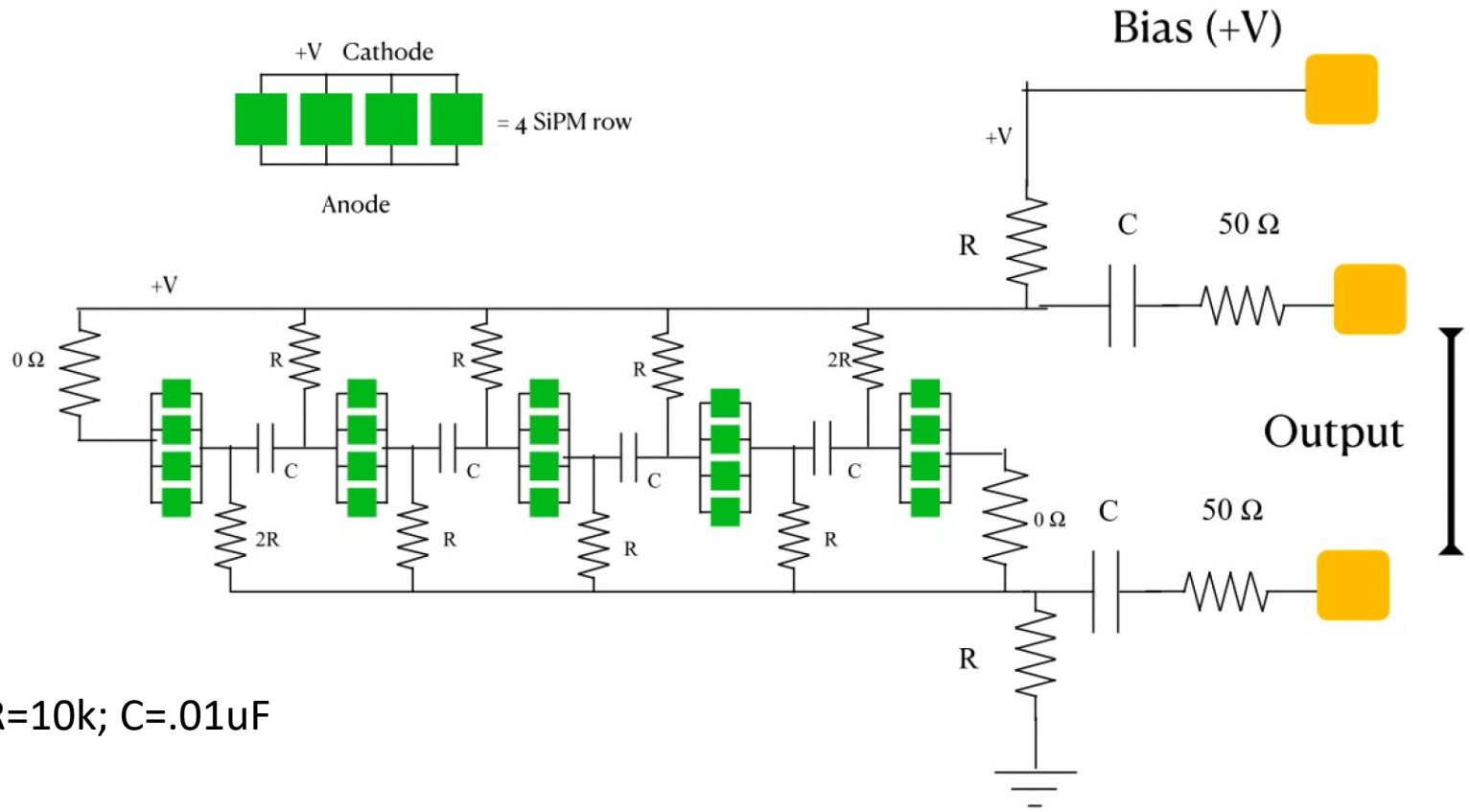
Outline

- SiPM hybrid (parallel/series) passive ganging
- Signal processing for cathode-mounted modules (including one complication)
- Signal processing for membrane-mounted modules
- Unexpected problems

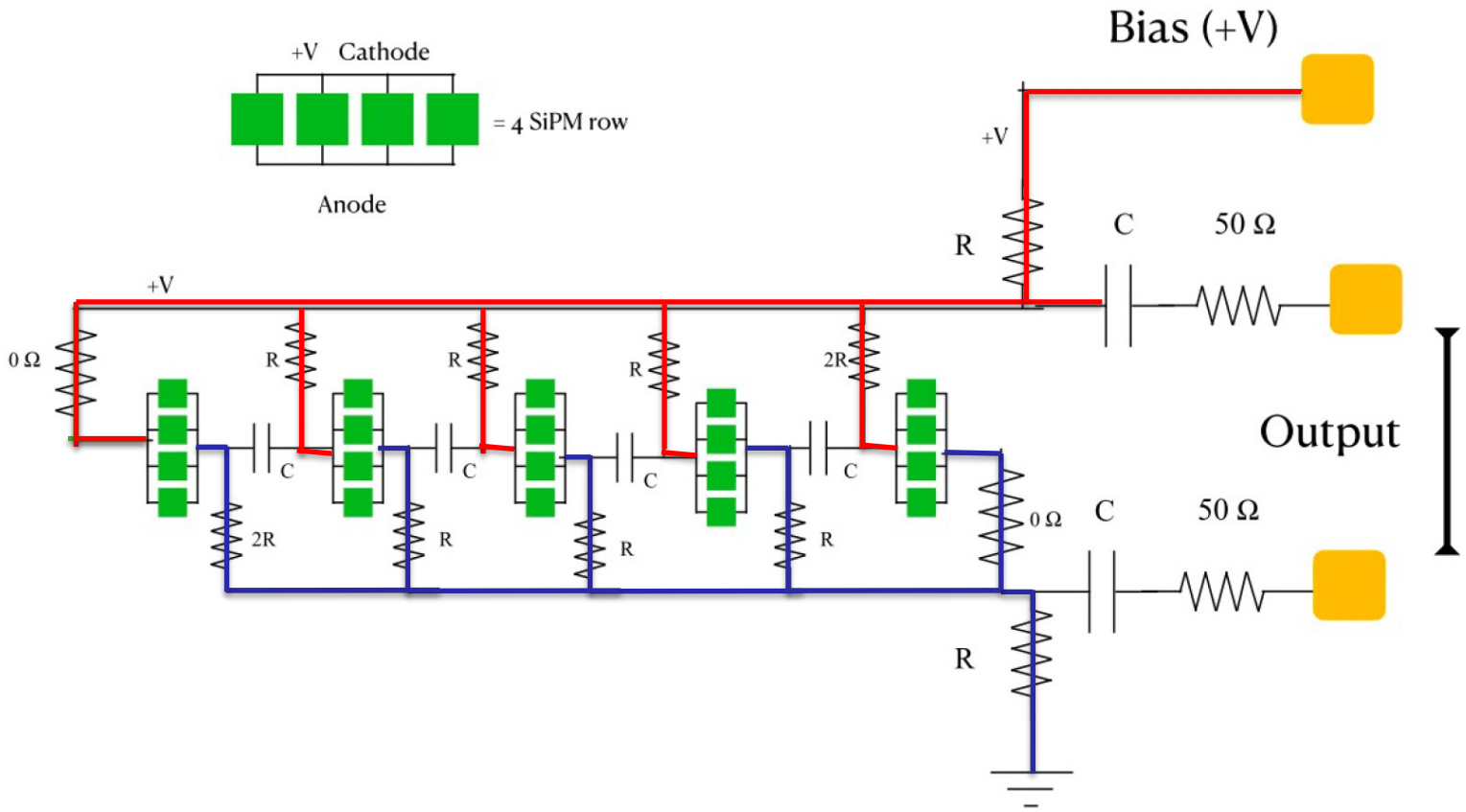
Hybrid Passive Ganging of SiPMs



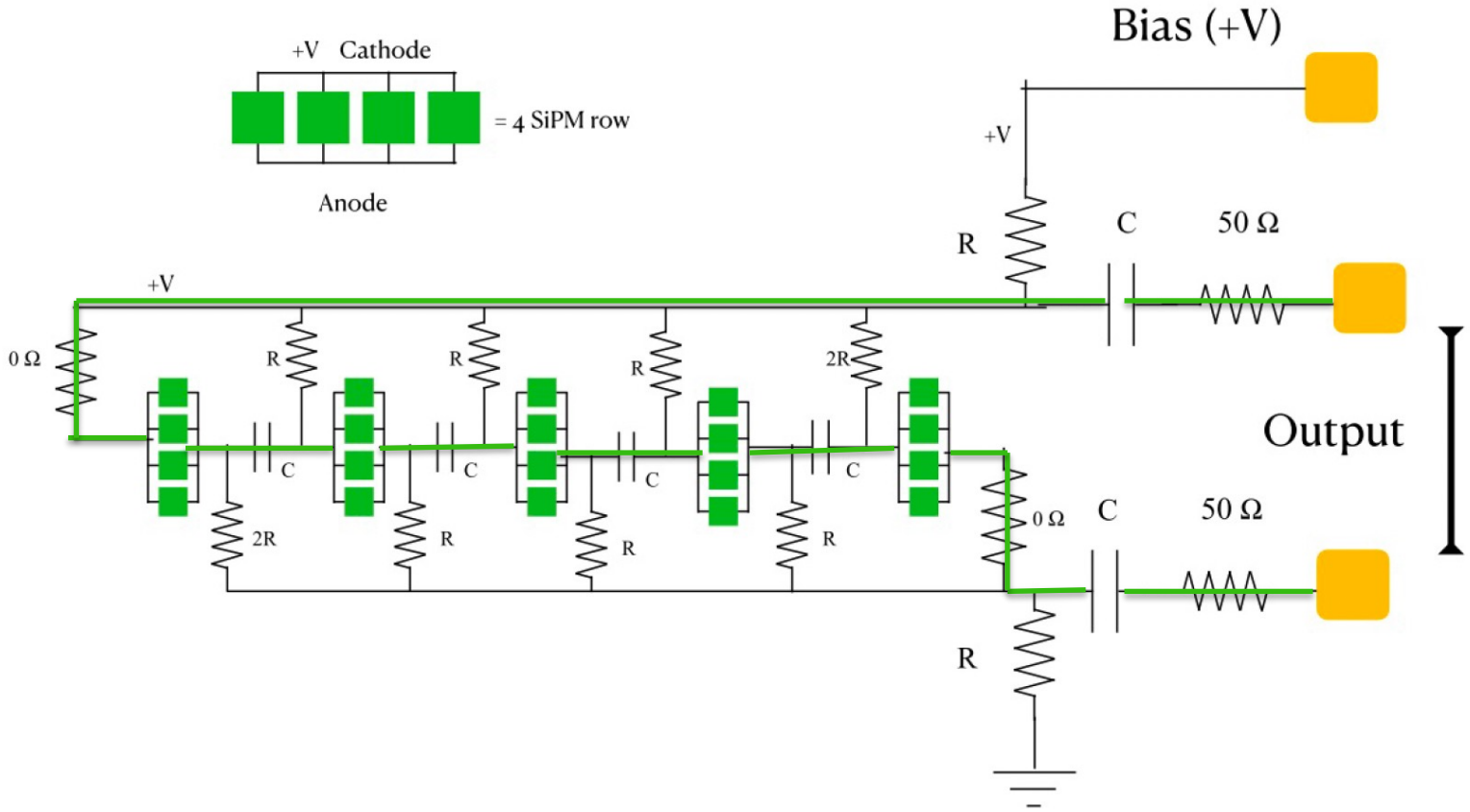
R=10k; C=.01uF

Picture from D. Tonani & G. Cancelo 11/17/21; inspiration from K. Ieki (XeSAT 2017)

Bias voltage is delivered in parallel to all 20 SiPMs (No high voltage required)



Readout path is through 5 groups of 4 SiPMs in *series*; Signal is shorter than if all 20 were in parallel (capacitance adds in parallel)



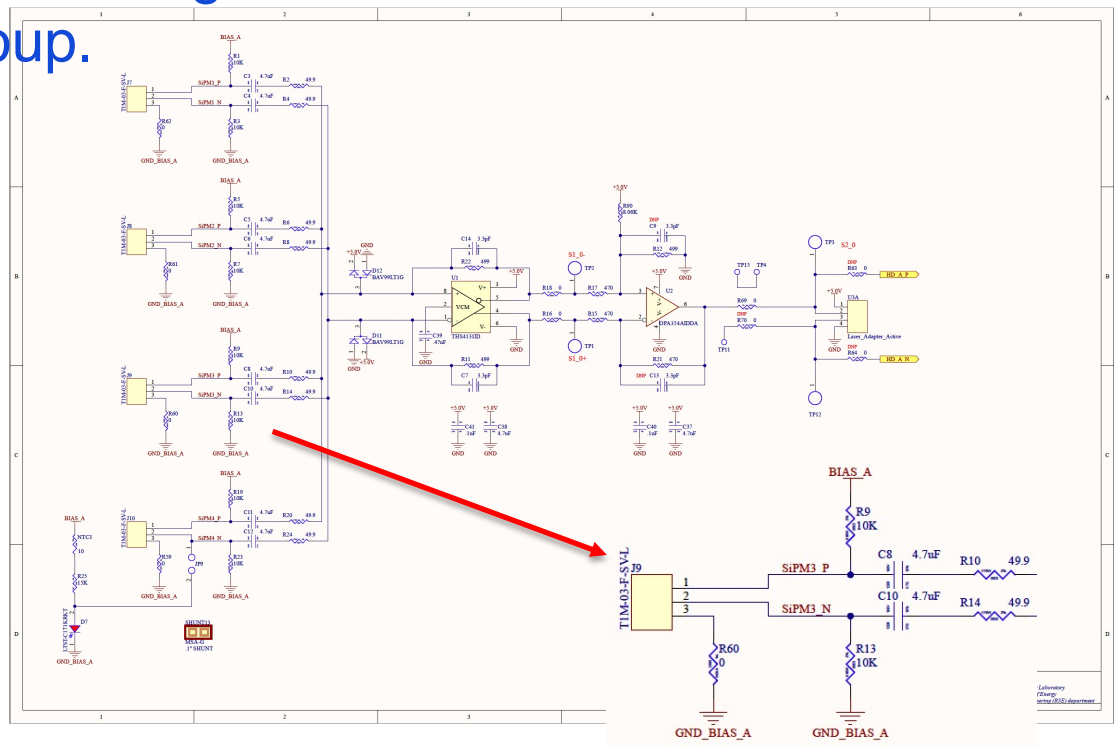
Hybrid ganging yields good S/N with a larger number of SiPMs than is possible with parallel ganging while using the same bias voltage.

Cathode Mounted Modules – Signal Processing

- Structured as a motherboard with daughter cards to facilitate parallel development of key components
- Active ganging 1st stage: op-amp with ~10x voltage gain
- 2nd stage establishes DC offset for laser diode (SE output)
- 3rd stage (laser driver) on daughter card.
- Design led by APC group.

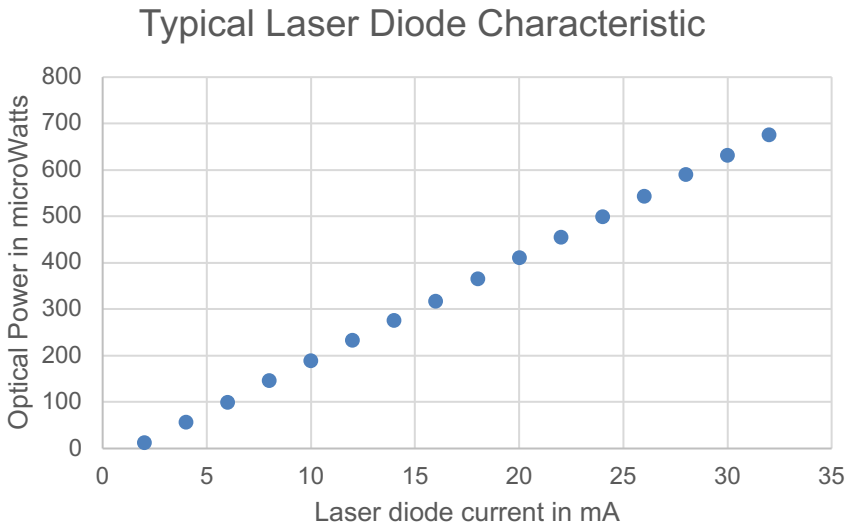
Decoupling capacitors are on the “DCEM” to minimize the number of components on the SiPM flexible circuits.

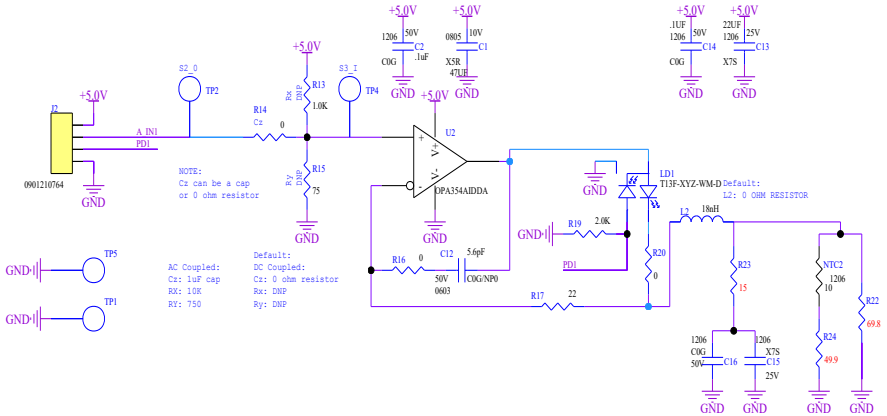
DCEM has 2 identical channels; each corresponding to 80 of the 160 SiPMs in an XArapuca module.



Cathode Mounted Modules – Laser Diode Characteristic

- The plot on the right shows the light output at LAr temperature as a function of diode current (measured after a length of 62.5 micron diameter multimode optical fiber).
- Since the SiPM signal is mostly unipolar, we bias the laser driver circuit so that the laser current with no signal is ~ 4 mA and arrange the circuit so that signals are positive going.





Cathode Mounted Modules – Outside of Cryostat

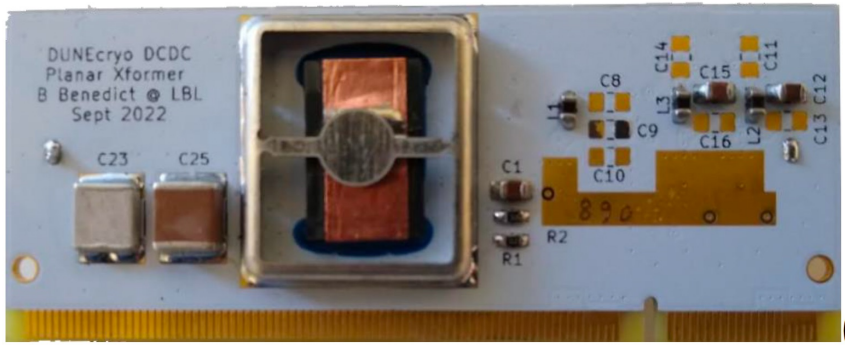
- Optical signals are converted to electrical using a photodiode (board sold by Koheron includes also a transimpedance amplifier).
- DAPHNE will digitize the signals and interface with the DAQ system.
- We plan to design a version of DAPHNE in which the optical to electrical conversion replaces the differential to single ended conversion at the input of DAPHNE.
- Alternatively, we could continue to use a separate module, which might even consist of Koheron cards.

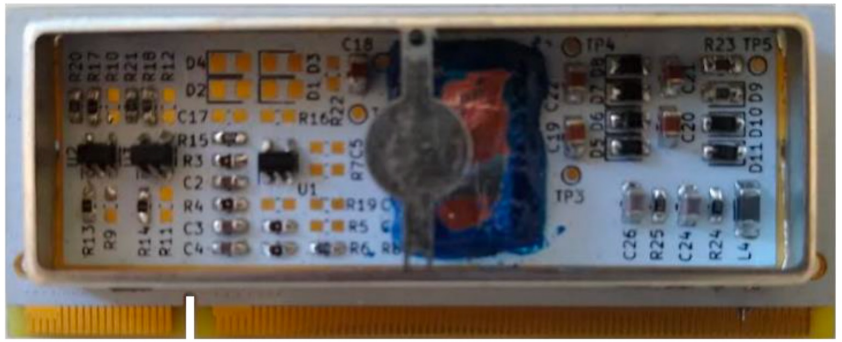
Cathode Mounted Modules – SiPM and circuit bias

- Early versions of the optical readout used 3 “Optical Power Converters” in series (with a Zener diode circuit to set the output voltage) to bias the SiPMs.
- DCEM provides for up to 4 OPCs with jumper options to allow flexibility in how many are used for SiPM bias and how many are used for circuit bias.
- Typically, 1 OPC (with a voltage regulator to set the output voltage) is used as input to a DC/DC step-up converter which generates the SiPM bias voltage.
- Typically, 1-2 OPCs (with a voltage regulator to set the output voltage) is used to bias the readout electronics.

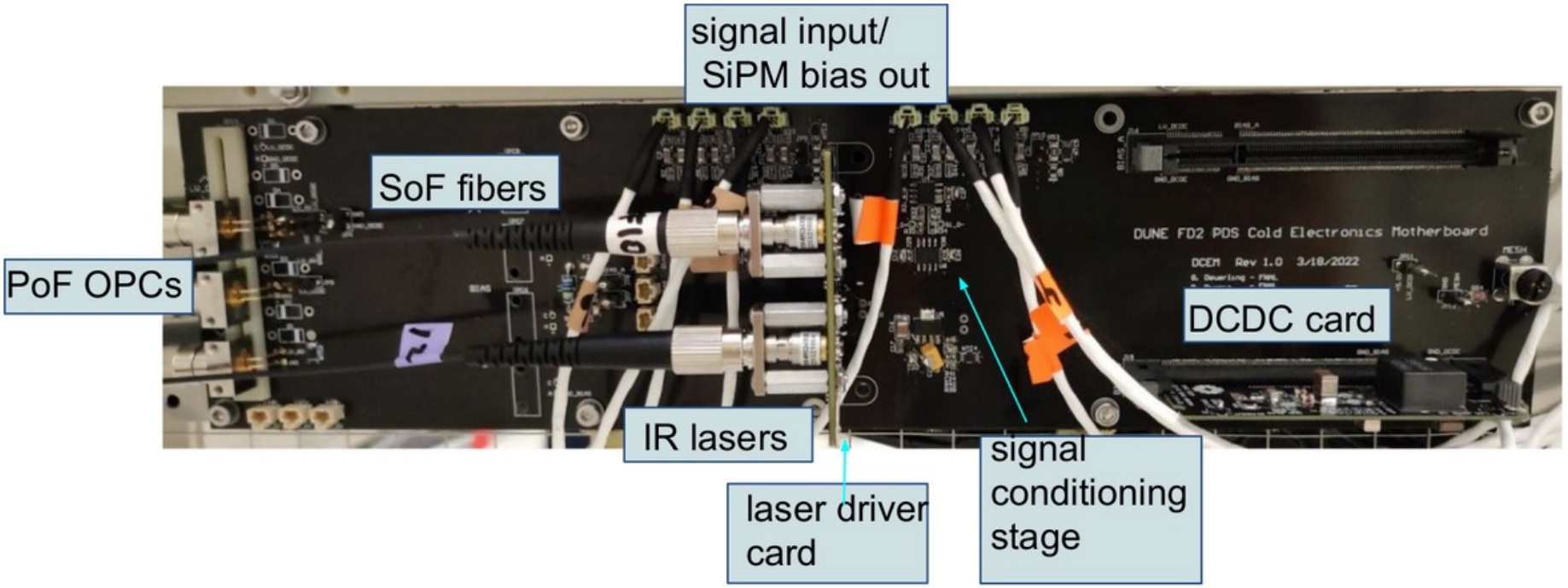
Cathode Mounted Modules – DC/DC Step-up Converter

- Multiple DC/DC converter development paths have been pursued simultaneously.
- One cryo-compatible commercial option was identified (Pico).
- Successful circuits have been designed and implemented by a group at LBL and also by a group at INFN Milano.
- LBL version shown at right (top view, bottom view, & with RF shield).
- ProtoDUNE-II (Vertical Drift) will include both LBL and INFN versions.



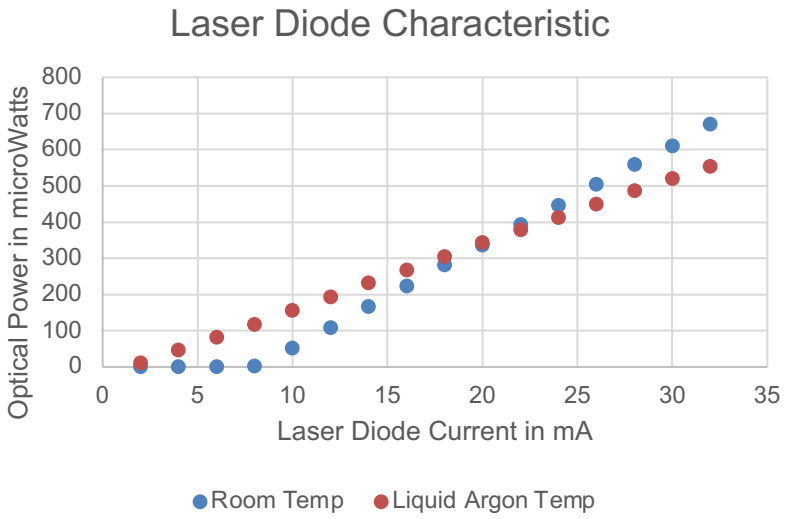


Signal Processing – DCEM for Cathode Mounted Modules

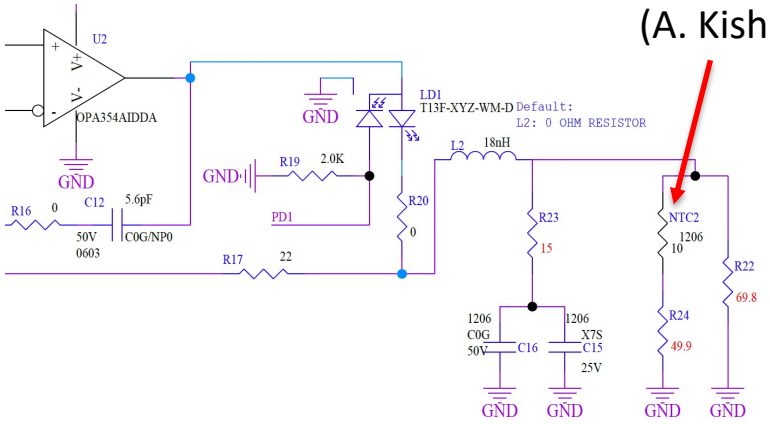


Complication & Solution

- Need to verify that XA module and readout are operational after installation and before the cryostat is sealed, but…
  - SiPM breakdown voltage is lower cold than at room temperature.
  - Laser diode threshold current is lower cold than at RT.
- Solution: Use resistors with large negative temperature coefficient (NTC) to allow electronics to passively switch between cold & RT configurations. NTC resistors are essentially open switches at cryogenic temperature.

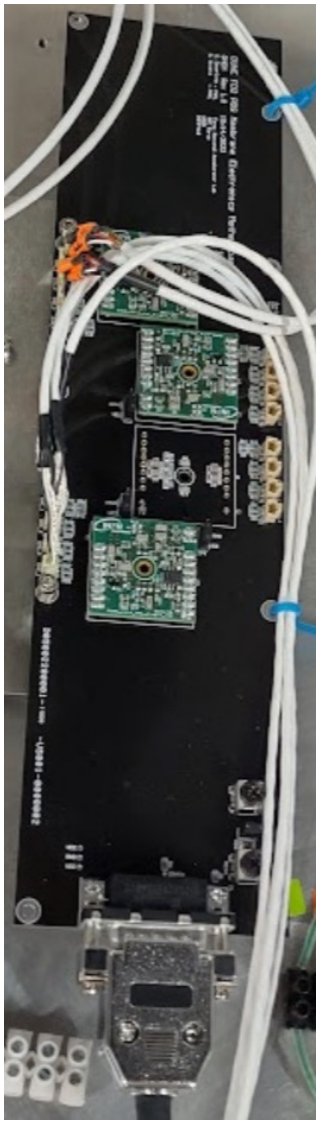


NTC2 is 10 Ohms at RT; very large in LAr (A. Kish)



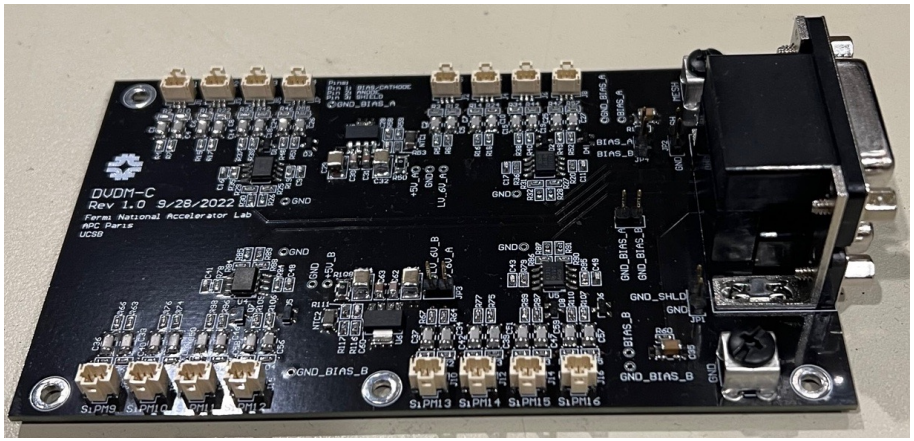
Signal Processing for Membrane Mounted Modules

- Horizontal-drift style (default option):
- Modified version of DCEM distributes input signals from 2 XAs to 4 HD cold amplifiers (same daughter cards as used in the HD XAs, but with slightly modified feedback).
- 1 Readout board will be located between 2 membrane-mounted XAs
- Outputs/bias circuits are routed on the DCEM to a single 15-pin D connector.
- SiPM Bias and CE power is provided by DAPHNE.
- The I/O cable is compatible with DAPHNE.
- Board on the right has 3 of 4 HD-CE amplifiers mounted.



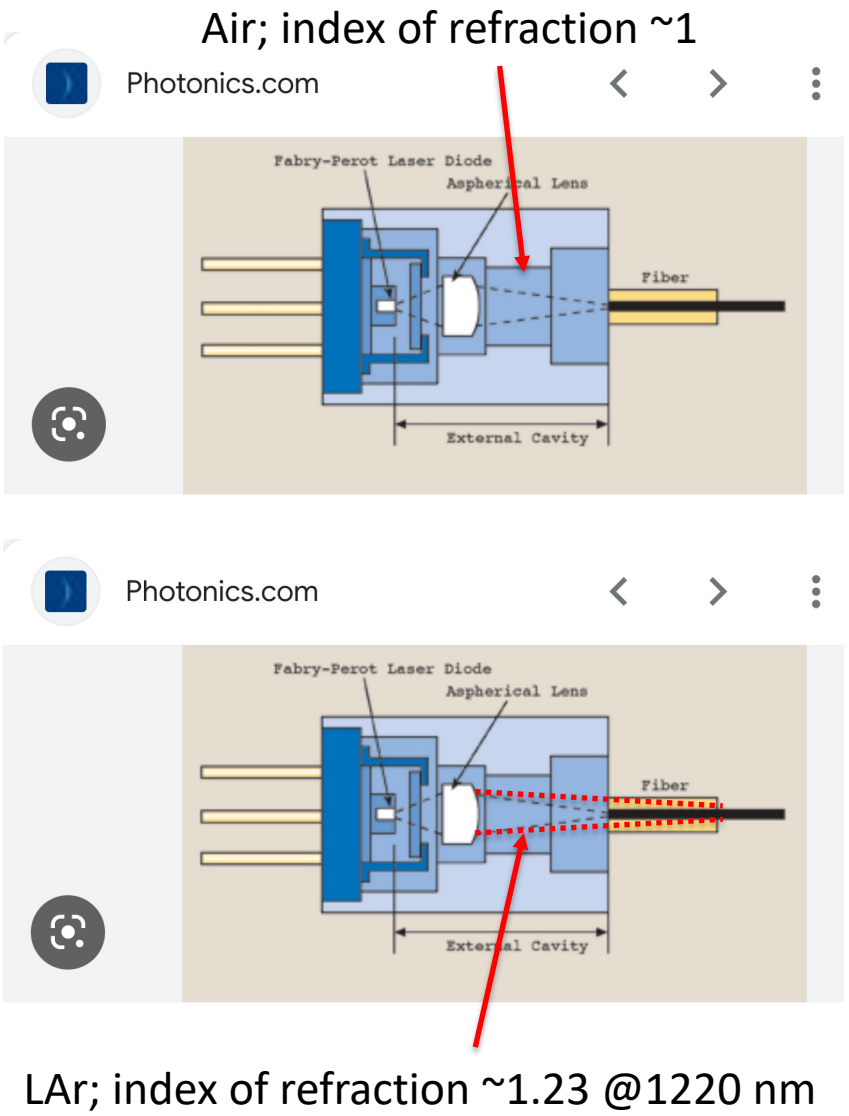
Signal Processing for Membrane Mounted Modules

- Vertical-drift style readout of membrane-mounted XAs will also be deployed in PD-II.
- Modified DCEM with differential output directly from the 1st ganging stage.
- I/O is compatible with DAPHNE if very minor modifications are made to the DAPHNE input stage (to separate signals from SiPM bias).
- SiPM and CE bias provided by DAPHNE
- Two twisted-pair cables are required for a 4-channel readout board, which is located between 2 membrane-mounted XAs.
- Can also be read out using a warm board that is similar to the 2nd stage of the DCEM (will be used in cold box tests with CAEN digitizer)



Unexpected Problem - Laser Diodes

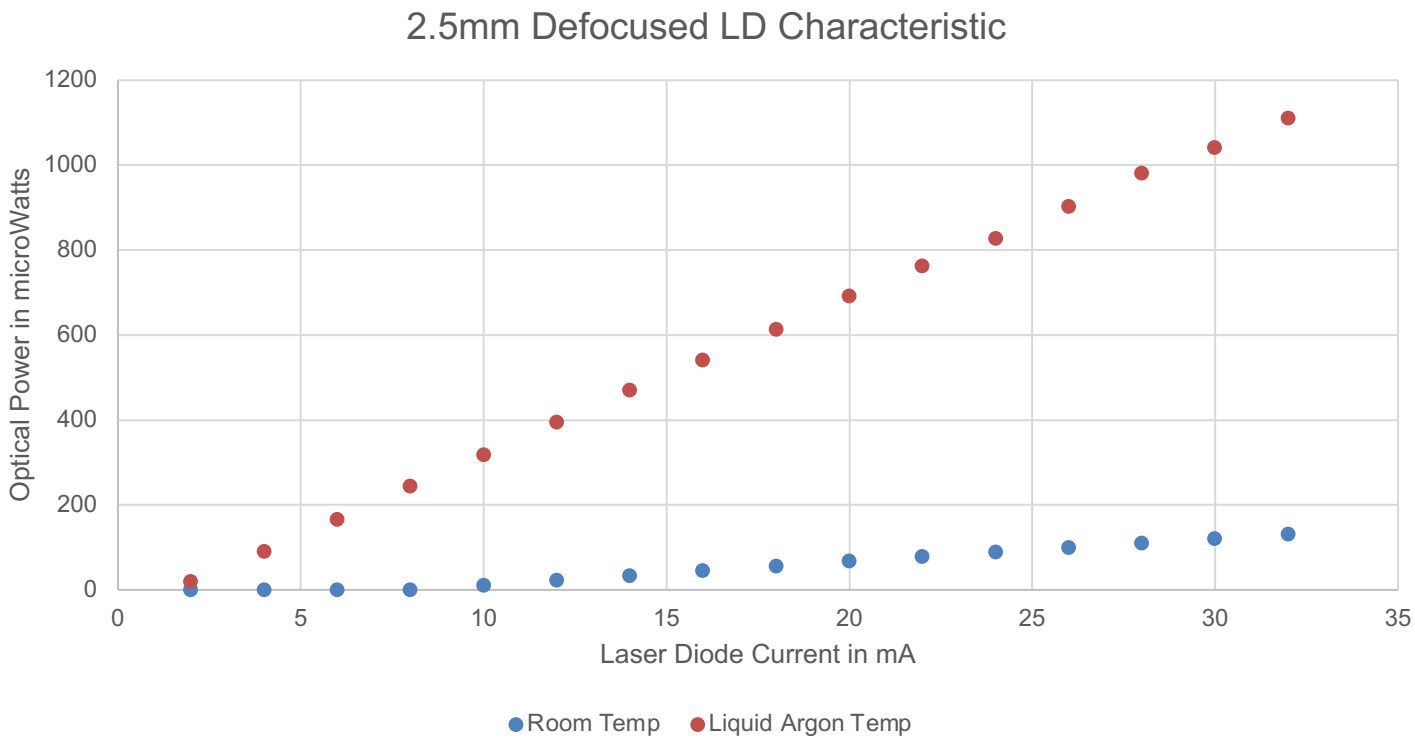
- The first FC LDs that we got from Lasermate produced much less light in the NP02 cold box run in Dec 2021 than in our tests with (shallow) LN2.
- The next batch of LDs from Lasermate produced essentially no light in a subsequent cold box run.
- We eventually understood that the problem was that the LD package became flooded with liquid argon.
- This changed the optics such that much less light was captured in the (very fine) single mode fiber used in the package.
- In response to a question, Lasermate said that they had changed the lens type between orders.



Flooded Laser Diode Problem

- We tried sealing the LD package using cryogenic compatible epoxy.
  - This worked for a while… but eventually failed.
  - Lasermate agreed to produce sealed LDs for us… but they also used glue and their FC and pigtailed diodes all eventually failed. We did some tests in a pressurized dewar and failure occurred sooner than in relatively shallow liquid argon.
- Lasermate would not share the size or divergence of the Fabry-Perot laser diodes and would not share the lens shape or any other details of their package… but they did agree to produce samples in which a hole was made in the wall of the package to facilitate liquid argon infiltration and the fiber was moved away from its nominal position by 1mm and 1.5mm.
- We measured both types and found that the 1.5mm defocused LDs produced more light at the end of an optical fiber in deep liquid argon than in air.
- We then purchased a series of LDs with defocus distance between 1mm and 2.5mm (the maximum that Lasermate was willing to produce).
- The 2.5mm defocused LDs are best in LAr and produce enough light in air that the function of the module can be verified at room temperature.

Flooded Laser Diode Solution



- This LD is made with a 2mW class diode → the light yield is ~50% of what it would be with optimal optics.

Unexpected Problem – Capacitor Failures

- We selected capacitors based on a list of components proven to be suitable for cryogenic use.
- Nonetheless, we have had a number of capacitor failures.
- This issue is now top on our list of problems to solve.
- The problems have been associated with 4.7 uF X7S surface mount capacitors.
- All of the DCEMs used recently have been assembled by hand.
- The problem may be related to CTE induced stress associated with use in liquid argon, exacerbated by stress on the capacitor related to heating it with a soldering iron while the PCB as a whole is not heated.
- We have recently had two DCEMs assembled at U. Iowa using the reflow oven in their Electronics Assembly Shop.
- We are confident that we will fully understand this problem soon and that it will be easy to solve.

Backup Slides

Parts Identifiers on PCBs