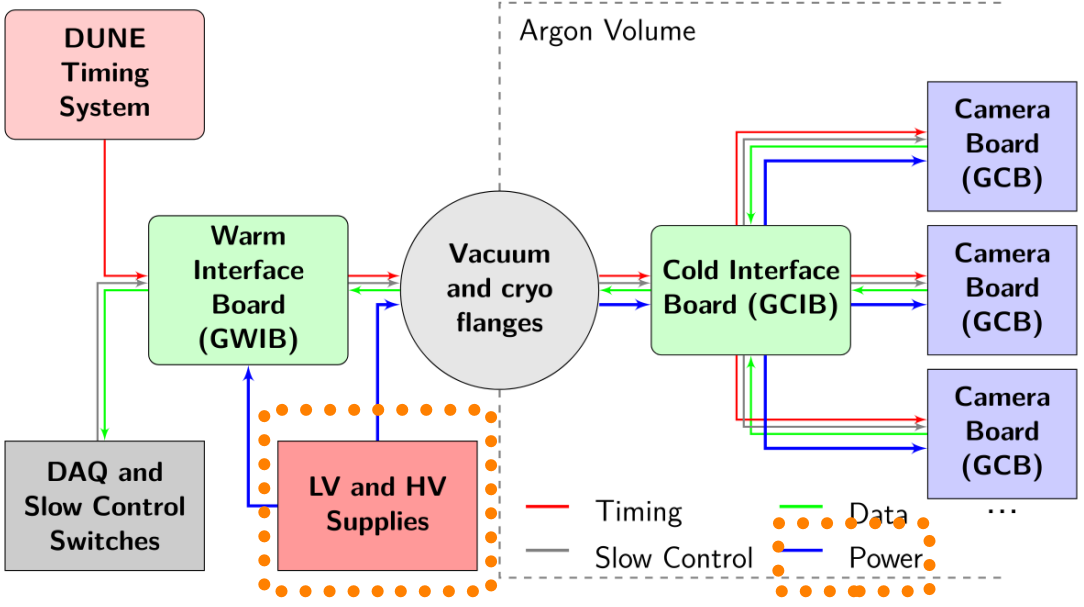
GRAIN Feedthroughs and power mockup

Nicolò Tosi – INFN Bologna

DUNE Italia 11/11/2025

Part 1: Powering challenges



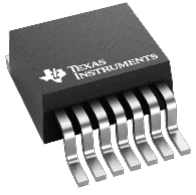
Powering DENEB in GRAIN

- DENEB uses a reasonable amount of power, but requires this power at a low voltage and high current:
  - Analog Vdd @1.2V: ~1 A when off, ~8 A working
  - Digital Vdd @1.2V: ~4 A when off, ~8 A working

- Supplying this power would be trivial without
  - Cryogenic Immersion and cryostat penetration
  - Magnetic Field
  - Rapid cycling to reduce heat load (settling < 1 ms)

Cryo regulator on camera board

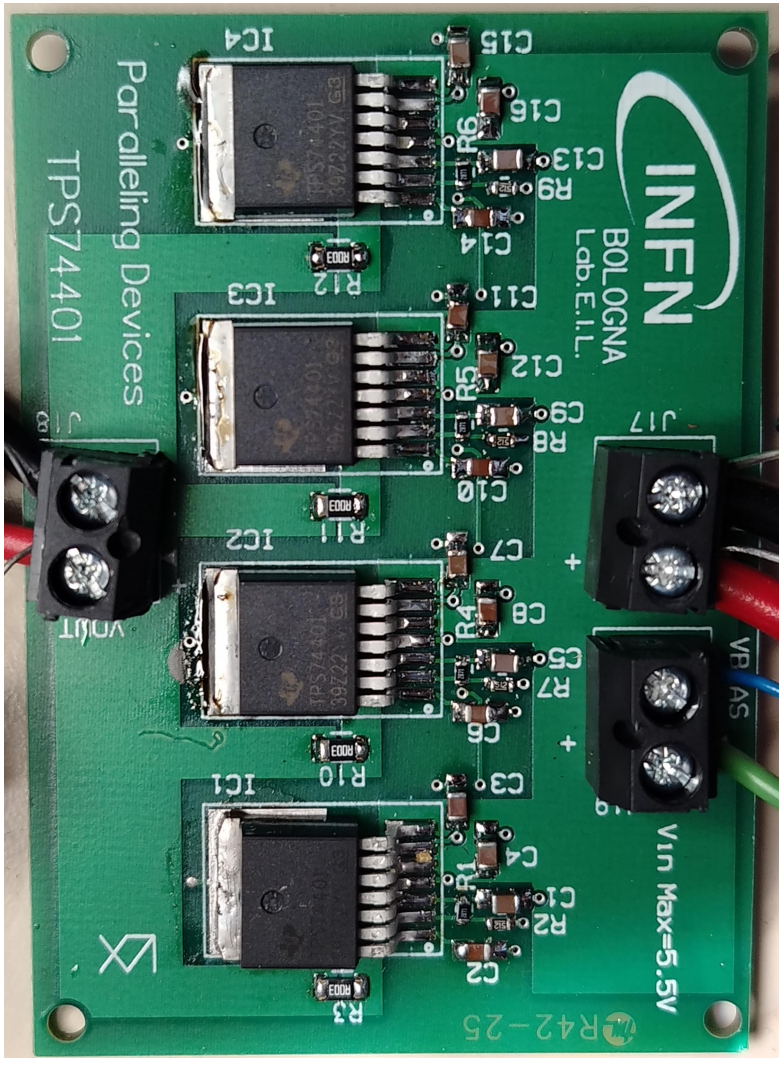
- We have not found any cryogenic Switching regulator
  - would allow conversion of reasonable currents at higher voltages
  - would also need to work in B field – not trivial
- Very few models of cryogenic linear regulators known to exist
  - None of these supply even close to 8A
  - Best candidate is Texas TPS74401 supplying 3A
  - Paralleling works but has downsides (worse load regulation)



- Designed a test board to exercise parallelization
  - Board is ready, will require systematic testing

LDO test board

- Four regulators in parallel
  - Up to 12A
- Very first cryo bath OK
  - Tested only up to 7A
  - Some limits from test setup
- Ballast resistors cause mediocre load regulation
  - Improves a bit by itself in cryo
  - Can use smaller R

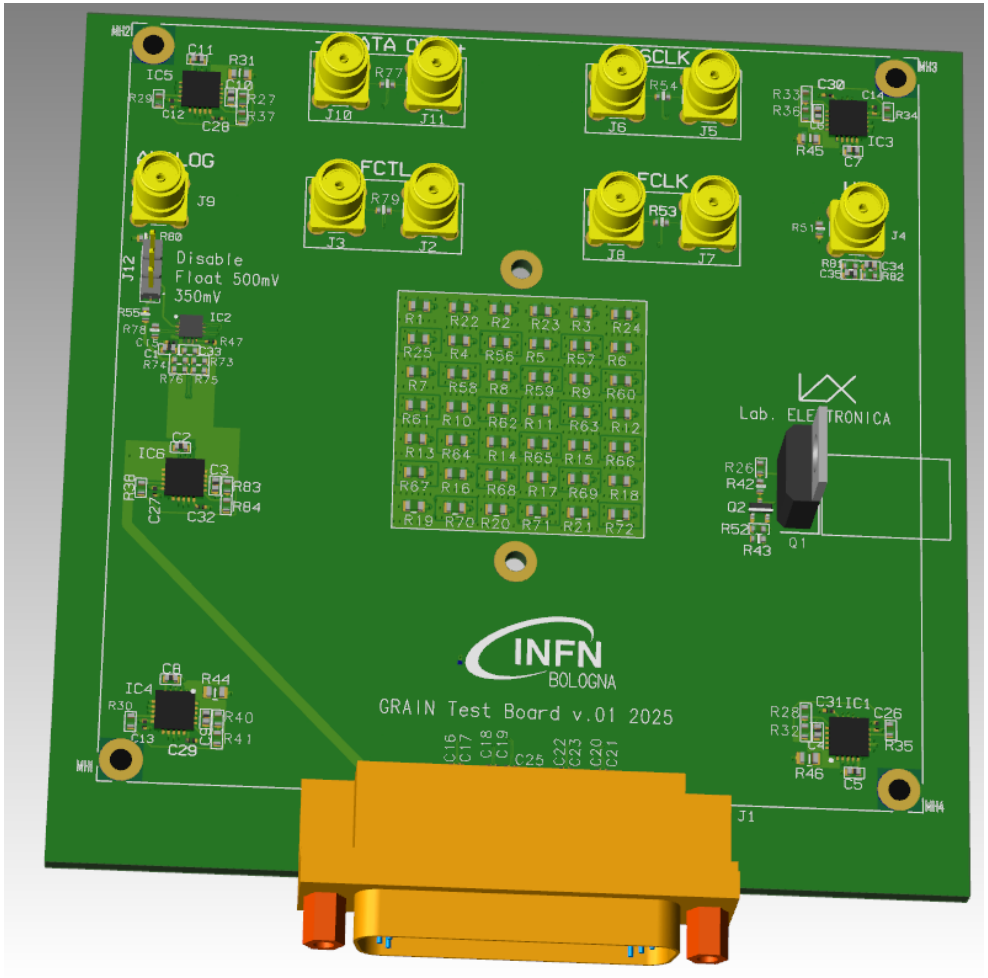


End goal: full power mockup

- Mockup boards were planned for end of this year
  - The increase in power caused us to redesign the power system
  - Search for more powerful LDOs took a few months
- Todo by 2025: intermediate test with 4-LDO board
  - Measure performance up to max current, stress test few weeks
  - Measure settling time for power gating, high cycle count
  - Work on improving load regulation
- Q1 2026: complete redesign of mockup boards
  - Incorporate also changes in connectors (see part 2)

The mock-up

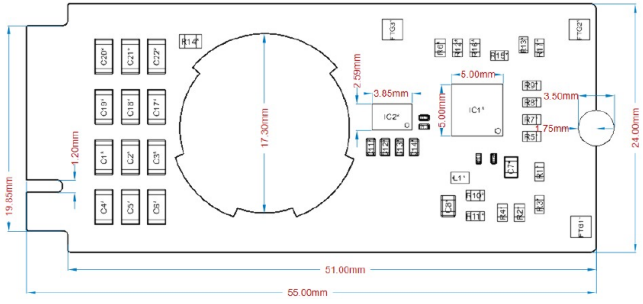
- Old design lower power
- The mock-up is sized like a real GCB
- Excessive number of layers (18), to spread heat from the central region (would be needed for routing in the actual GCB)
- Mock connection via the D-Sub, test via SMA



The rest of the power chain

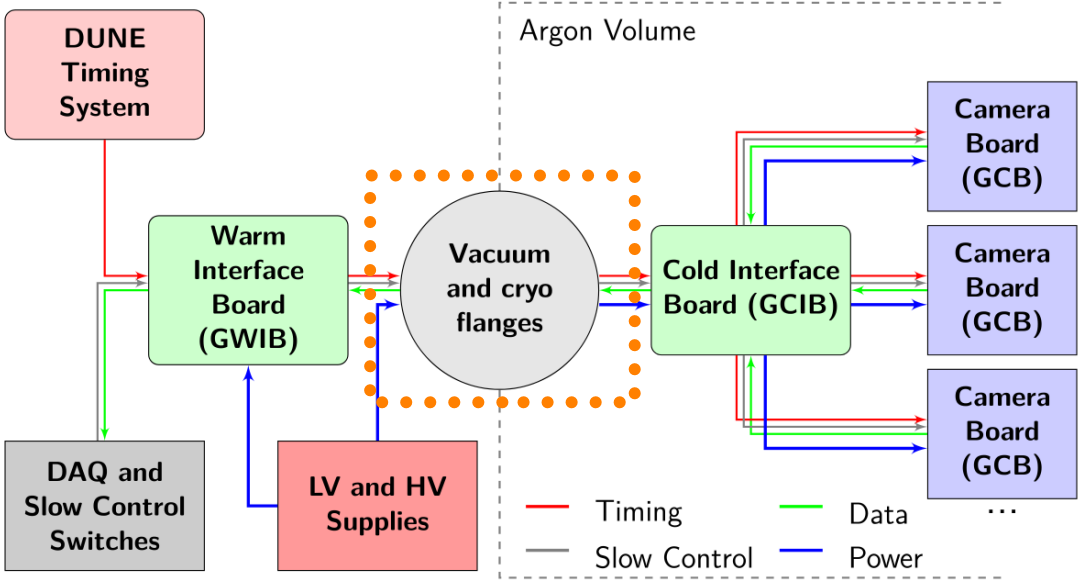
- Option: use a warm, B-field tolerant switching regulator on the GWIB?

CERN bPOL-48V
Air Core Inductor



- With regulator:
  - More efficient, possibly less expensive (fewer CAEN boards)
  - Needs testing, design effort
- Without regulator
  - Simpler, possibly more robust
  - Thicker cables, more wasted power

Part 2: Feedthroughs



Cryo-vacuum feedthrough

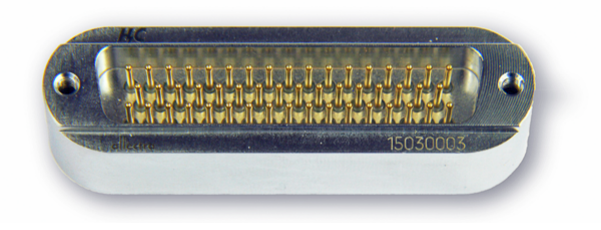
- Some issues with completely custom solutions
  - Lack of expertise on our side
  - Few if any actually submerged (mostly in gas, warmer…)
  - Unclear if we could formally meet certification standards
  - Relatively limited quantity to absorb R&D costs

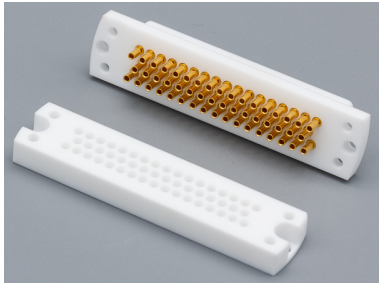
- Limited to catalog of available suppliers
  - Not the best match for our data lines requirements
  - Not space efficient on our small flanges

allectra
A future with vacuum

Power connections

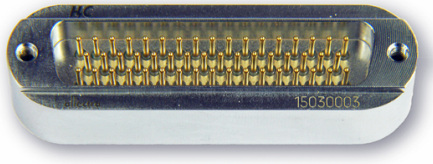
- Power for DENEB requires high current connections
  - Standard solution available: Sub-D High Current Pins, 6 A each
  - 2 x 50-pin connectors cover the eight boards per flange
  - Includes SiPM bias around 40V, auxiliary voltage(s).
- This is based on Allectra catalog parts:
  - Feedthrough, Kapton insulated wire, Ceramic cryo Connector





Data connections

- Commercial parts typically include:
  - Sub-D or similar multipin connector, no controlled impedance, mates with unshielded ribbon cabbles
  - Common coaxial types, of which the smallest is SMP, with 50 Ohm connectors and cables
- Critically: there is no ready-made 100 Ohm differential high-speed connectors
  - Either use 2 x coax => very costly
  - Develop our own based on available parts

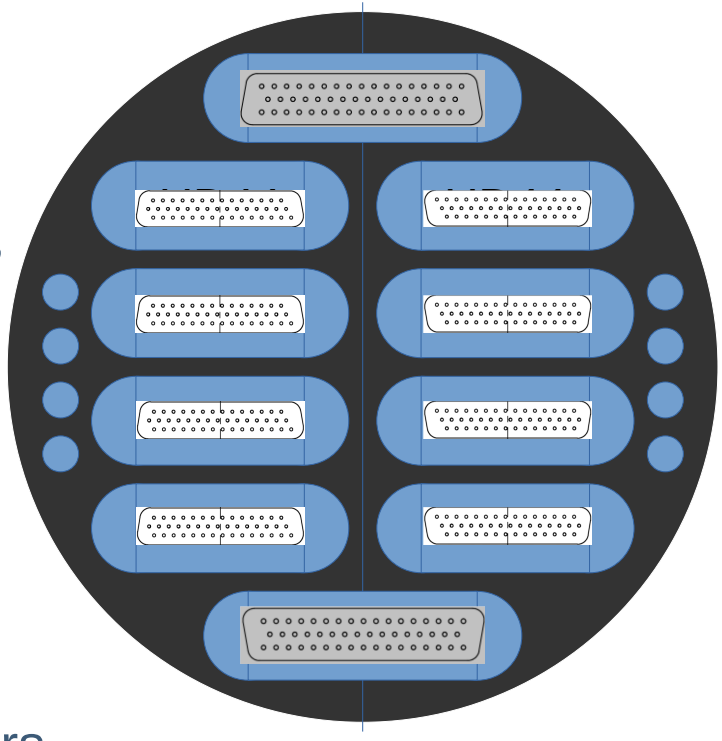


Data connections: requirements

- Most critical lines (>300 MHz B/W):
  - Analog port (our main test/calibration feature), 50 Ohm single
  - Clock port, 100 Ohm differential SLVS
- Other high speed lines (~300 MHz B/W):
  - Data port, Multifunction port, 100 Ohm differential SLVS
- Other lines:
  - Configuration, 3x, 100 Ohm differential SLVS
  - Reset, 100 Ohm differential SLVS

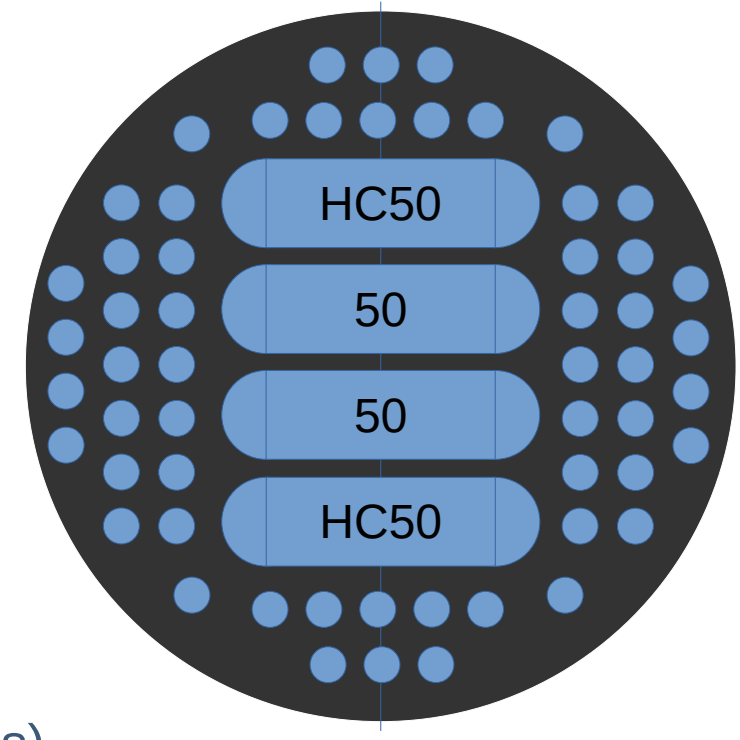
Data connections: semi custom

- Design:
  - High density Sub-D connector
  - Custom controlled impedance flex PCB
- Pros:
  - Least expensive (300-350k)
  - Allows independent connections
- Cons:
  - No catalog ceramic option for connectors
  - R&D risk. We have most components for test, delay with flex PCB



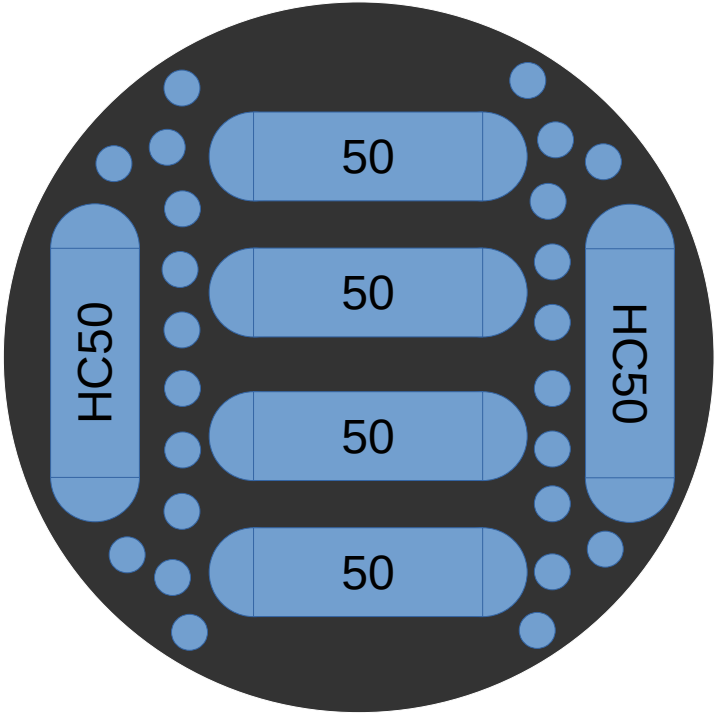
Data connections: coaxial only

- Design:
  - Sub-D connector for non critical lines
  - Coaxial for everything else
- Pros:
  - No R&D effort
  - No (very low) risk
- Cons:
  - Installation challenge (more than others)
  - Cost. Likely approaching 500k with cables and connectors



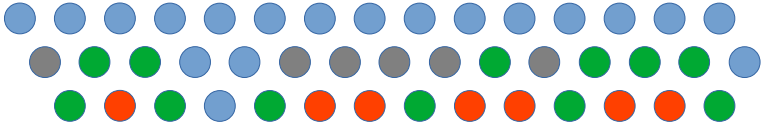
Data connections: Intermediate

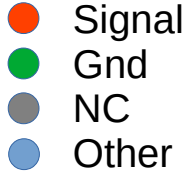
- Design:
  - Sub-D connector for most lines
  - Coaxial only for clock and analog
  - Flex PCB for less critical lines?
- Features:
  - Ceramic option available for Sub-D
  - Intermediate R&D effort
  - Intermediate risk
  - Intermediate cost (400k-ish??)

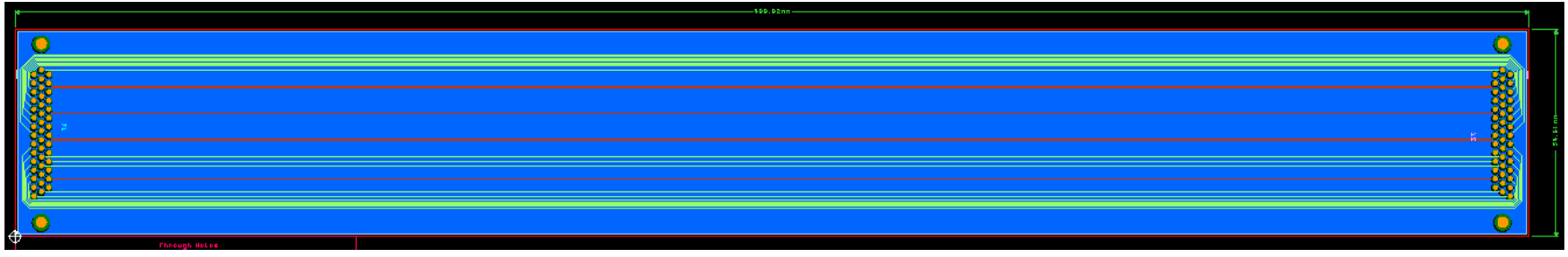


Kapton flex “cables”

- On order (now at >6 wks admin delay on the order...)
- Can test single ended 50 Ohm, Differential 100 Ohm in various configurations

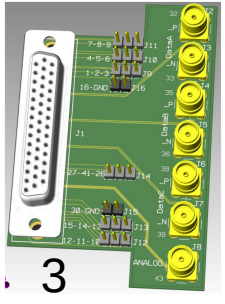


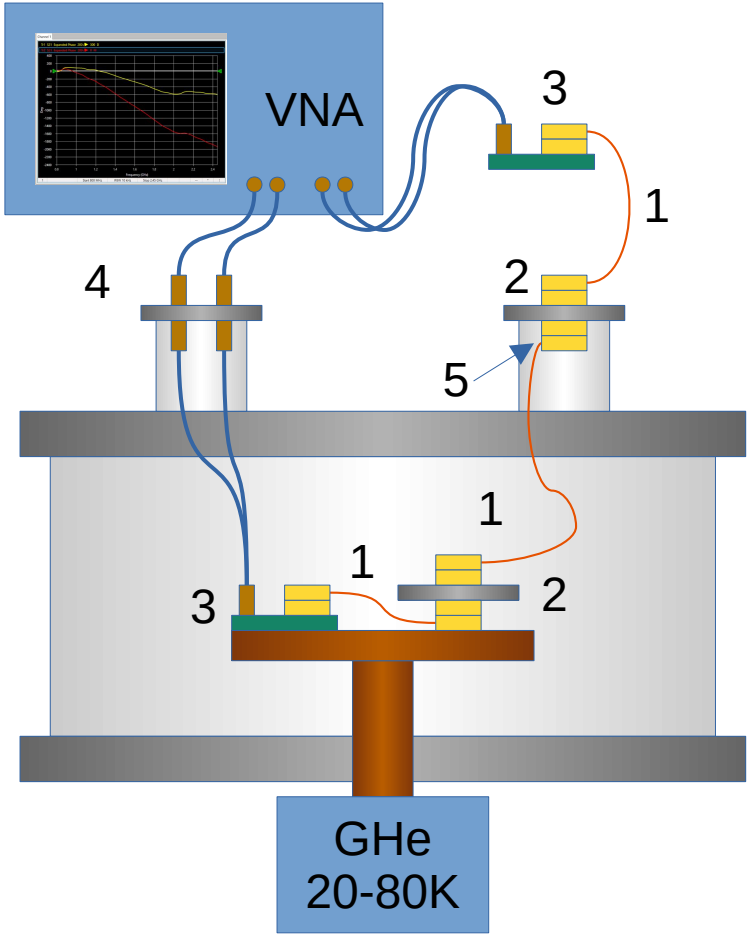




Basic test setup

- Cryo and vacuum combined
- Dry, but can go down to 20K
- Test Cable (1)
- D-Sub 44 HD feedthrough (2)
- Adapter PCB (3)
- SMA feedthrough (4)
- Most critical bend (5)

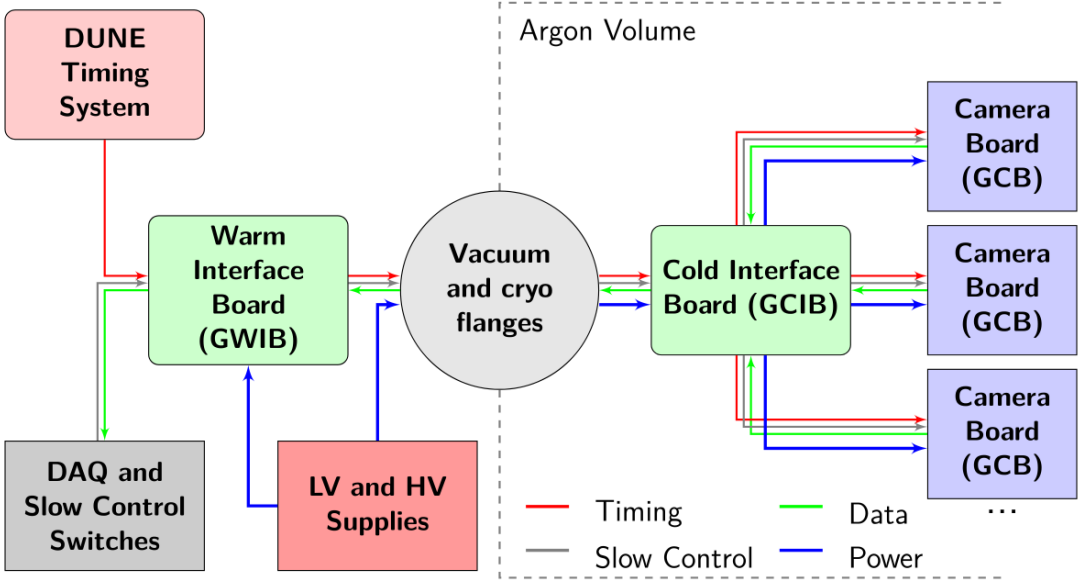




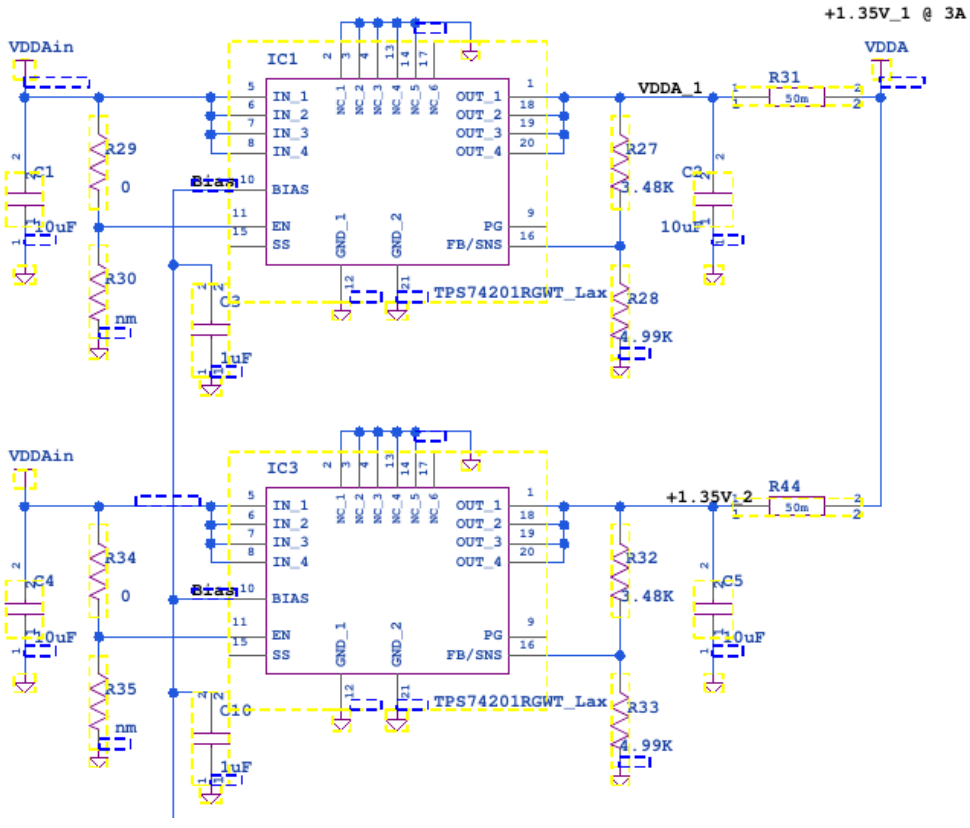
Tentative test plan

- Tests an individual connection chain in Bologna using LN_2 and the cold finger setup
- More extensively test the power scheme (including outer power supply, relevant for transients)
- All the missing components will be ordered before end of 2025 (assuming no further admin delays)
- Complete test setups should be available end of Q1 2026
- Full test protocols to be established

Backup


DUNE Timing System
Warm Interface Board (GWIB)
Vacuum and cryo flanges
Cold Interface Board (GCIB)
Camera Board (GCB)
Camera Board (GCB)
Camera Board (GCB)
...
DAQ and Slow Control Switches
LV and HV Supplies
Argon Volume
Timing
Data
Slow Control
Power

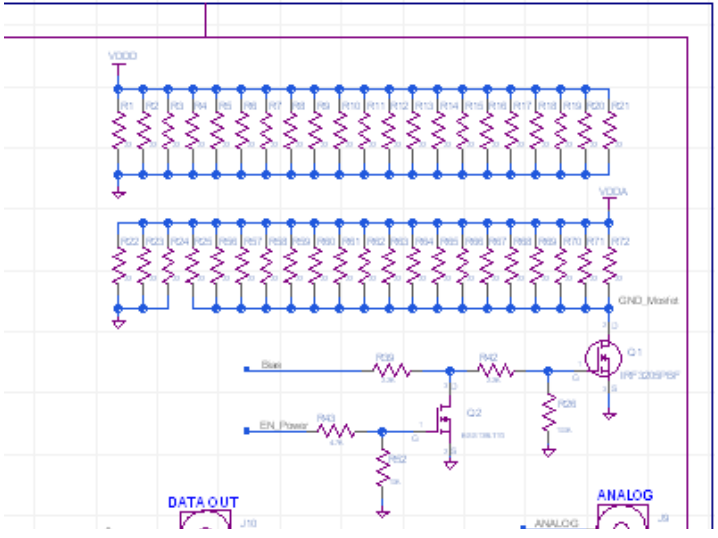
LDOs



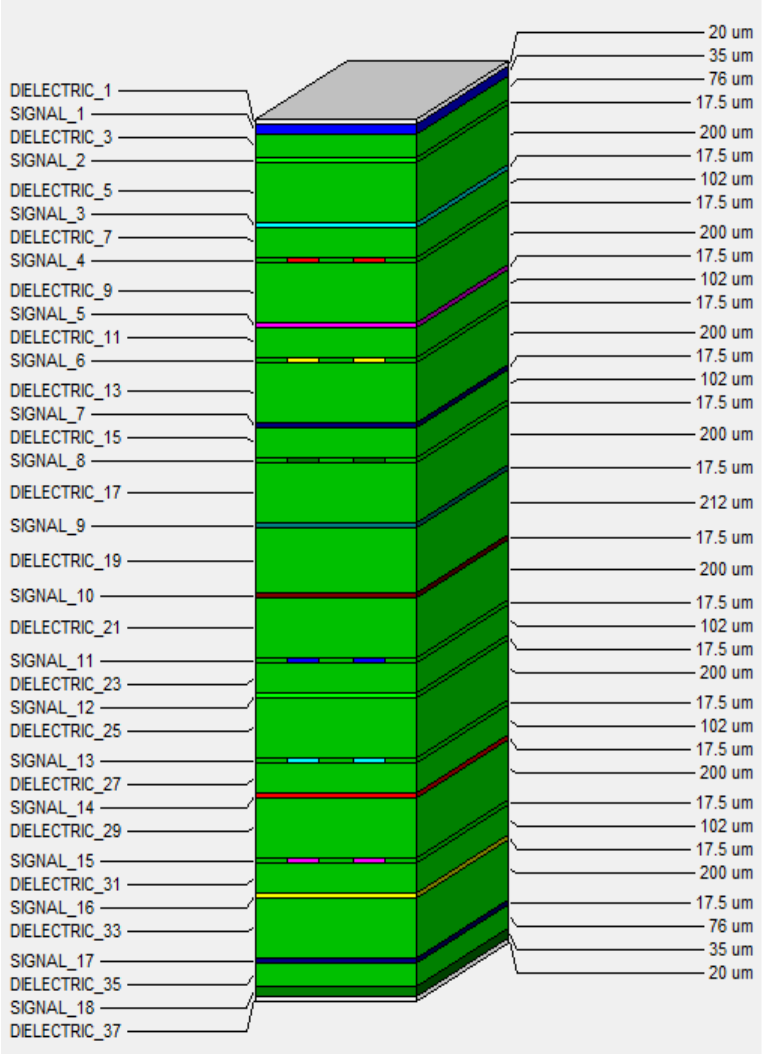
TPS74201

- Known to work in cryo
  - Iout max 1.5A
  - Vout 0.8 to 3.6V
  - Dropout < 100mV
- VddA: 2x LDOs @ 1.2V
- VddD: 2x LDOs @ 1.2V
- VddIO: 1x LDO @ 1.8V
  - Only used by LVDS/SLVS buffer

“DENEB”



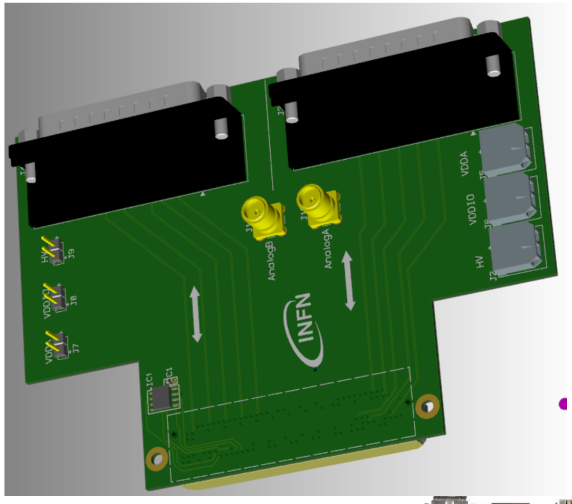
- Two sets of resistors in parallel
  - Default is ~1 Ohm per set
  - Set powered by VddD is always on, draws ~2 W
  - Set powered by VddA is enabled by mosfet, draws ~2W when on, ~0.2W when off
  - Set resistance will be adjusted to match real power draw
  - Layout and size matches ASIC size very roughly

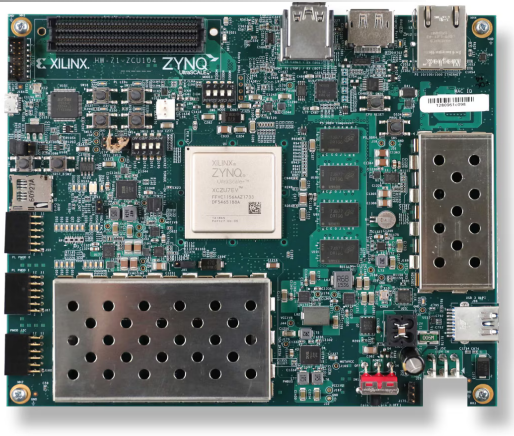


Layer\Net			Layer Usage	Plane Type	Plane Class	Plane Data State
Layer 1	...		Plane	Positive	(Default)	Dynamic
GND		○			(Inherited)	Dynamic
GND_Mosfet		○			(Inherited)	Dynamic
VDDA_1		○			(Inherited)	Dynamic
VDDA_2		○			(Inherited)	Dynamic
VDDD_1		○			(Inherited)	Dynamic
VDDD_2		○			(Inherited)	Dynamic
VDDIO		○			(Inherited)	Dynamic
VDDIOin		○			(Inherited)	Dynamic
Layer 2	...		Plane	Positive	(Default)	Dynamic
VDDAin		○			(Inherited)	Dynamic
Layer 3	...		Plane	Positive	(Default)	Dynamic
GND		◉			(Inherited)	Dynamic
Layer 4			Signal	Positive	(Default)	Dynamic
Layer 5	...		Plane	Positive	(Default)	Dynamic
GND		◉			(Inherited)	Dynamic
Layer 6			Signal	Positive	(Default)	Dynamic
Layer 7	...		Plane	Positive	(Default)	Dynamic
VDDD		○			(Inherited)	Dynamic
Layer 8			Signal	Positive	(Default)	Dynamic
Layer 9	...		Plane	Positive	(Default)	Dynamic
GND		◉			(Inherited)	Dynamic
Layer 10	...		Plane	Positive	(Default)	Dynamic
GND_Mosfet		◉			(Inherited)	Dynamic
Layer 11			Signal	Positive	(Default)	Dynamic
Layer 12	...		Plane	Positive	(Default)	Dynamic
VDDA		◉			(Inherited)	Dynamic
Layer 13			Signal	Positive	(Default)	Dynamic
Layer 14	...		Plane	Positive	(Default)	Dynamic
GND		◉			(Inherited)	Dynamic
Layer 15			Signal	Positive	(Default)	Dynamic
Layer 16	...		Plane	Positive	(Default)	Dynamic
GND		◉			(Inherited)	Dynamic
Layer 17	...		Plane	Positive	(Default)	Dynamic
HV_gnd		◉			(Inherited)	Dynamic
Layer 18	...		Plane	Positive	(Default)	Dynamic
HV		◉			(Inherited)	Dynamic

The FMC adapter

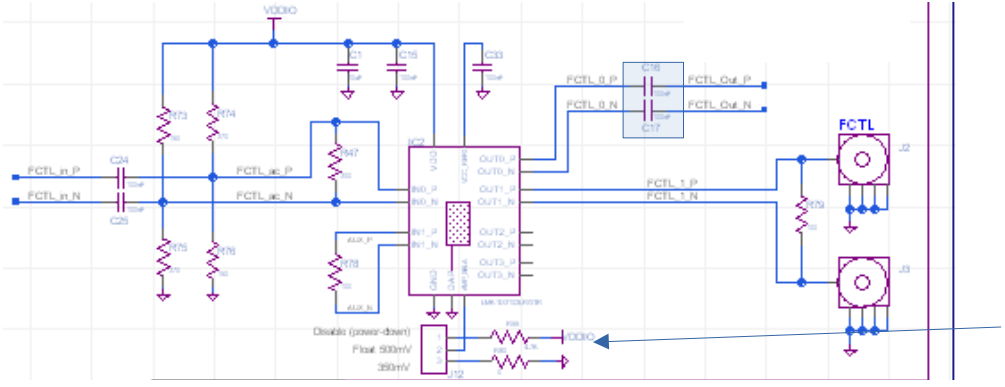
- Interfaces the ZCU104 development board with our cables on DB44
- Provides an SLVS compatible driver (the Zynq has a builtin compatible receiver)
- Separate input connectors for Power, HV
- Separate output for analog signal
- Usable on its own for thermal-only tests. How many do we want?
  - We can make it with 4 connectors too





“SLVS” Driver

LMK1D210xL



Schematic shown here is for mockup

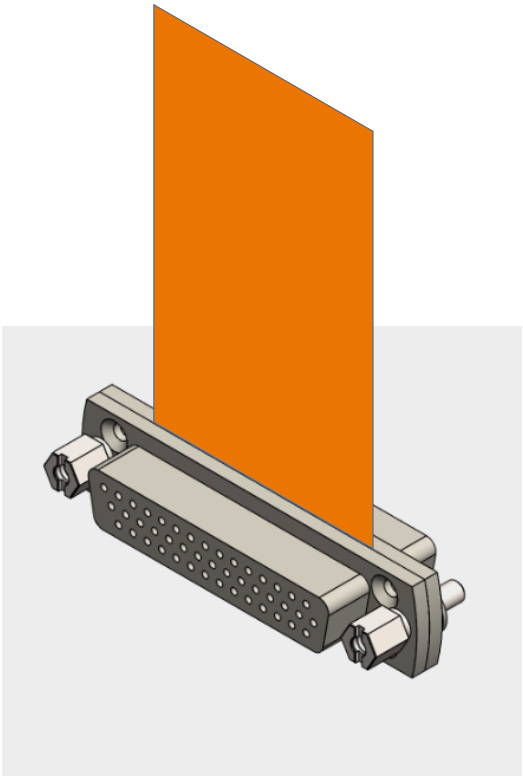
Can be used AC or DC coupled, if AC coupled we will test a “pulldown” termination that may be useful for fast control line

- I/O Buffer to have something to attach differential lines to...
  - Not quite SLVS (not available)
  - Input CM range 300-2300 mV, swing 300-2400 mV
  - Output CM 700 mV typ. (+-100)
  - Output swing adjust 350-500
  - Used in FMC to drive outputs
  - Used in Mockup for “active” loopback

DB44 and cables

- ~12-20 lines for DENEB I/O
- Others GND for impedance control, “shield”

Allectra commercial:
- no impedance control
- no shielding
- likely differential skew



Our idea:
- use Allectra connector, maybe modify top half
- insert multilayer kapton cable in the middle
- solder Allectra pins to the cable
- 50/100 Ohm traces, shield, power planes, ...