RNO station hardware

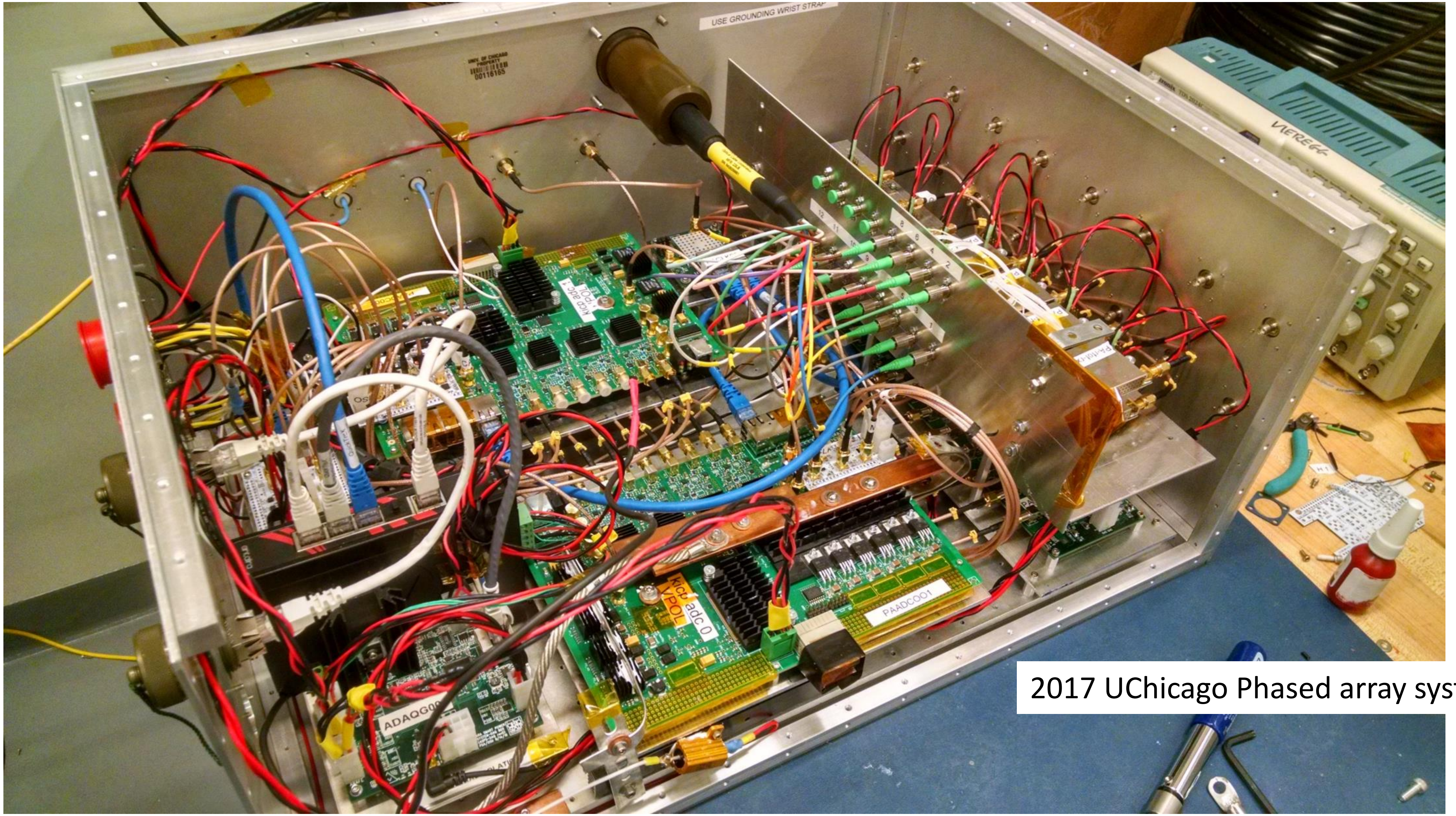
E. Oberla 2019-4-28

Will discuss RNO station hardware with a few key things in mind:

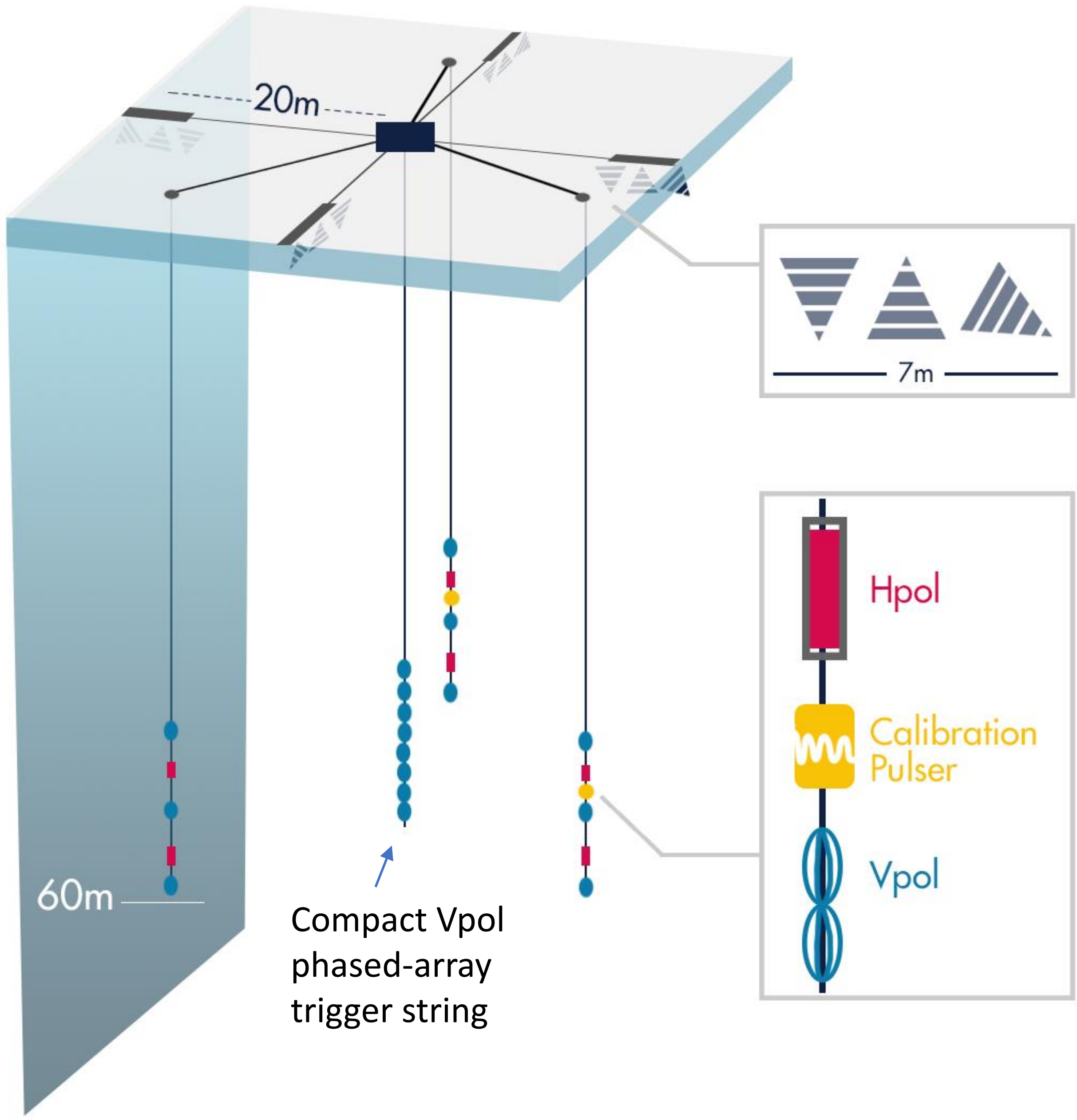
- Cost / reliability / scaling / meeting science targets
- The design of all RNO station components has to target large-scale production
  - >20 stations per year at height of RNO deployment. (61 total SP stations, several stations in the North)
  - Stations need to be ready-for-installation at time of shipping
  - ➔Automated test-stands for burn-in, reliability testing, and calibration

In addition to a production-oriented design from the onset, organized record keeping and databases will be crucial to having science-ready stations ready at the time of deployment.

This is not a Production Design



2017 UChicago Phased array system



RNO station sub-systems

1) Antennas + RF front-ends
2) RF Signal / power transport
3) DAQ [last-stage signal conditioning, digitization, trigger, control]
4) Calibration Tx
5) Station Power & Coms.
6) Environment enclosure / field access

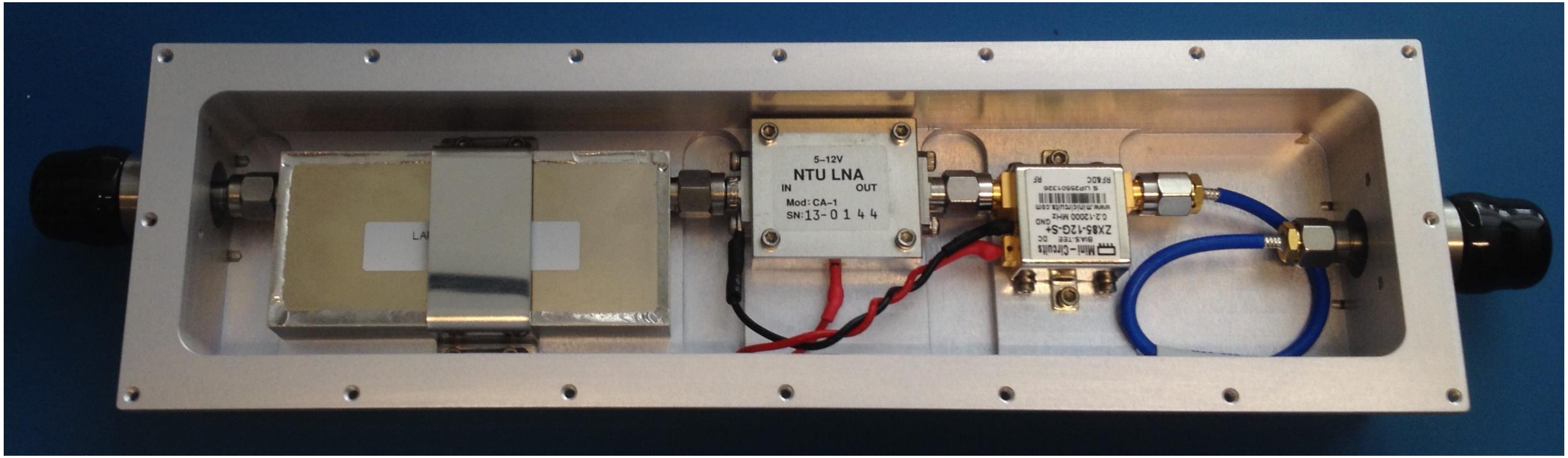
Antennas

- 9-12 surface LPDAs (off-the-shelf CLP-5130-2N)
- 17 deep Vpols + 1-2 calibration
  - ARA bicone?
- 6 deep Hpols + 1-2 calibration?
  - ARA ferrite-loaded quad-slot?

~650 deep antennas per year at peak RNO deployment.

Worthwhile to investigate alternatives that are more suited to mass production
i.e. fat dipoles, narrowband slots, etc. → requires input from simulations

RF front ends



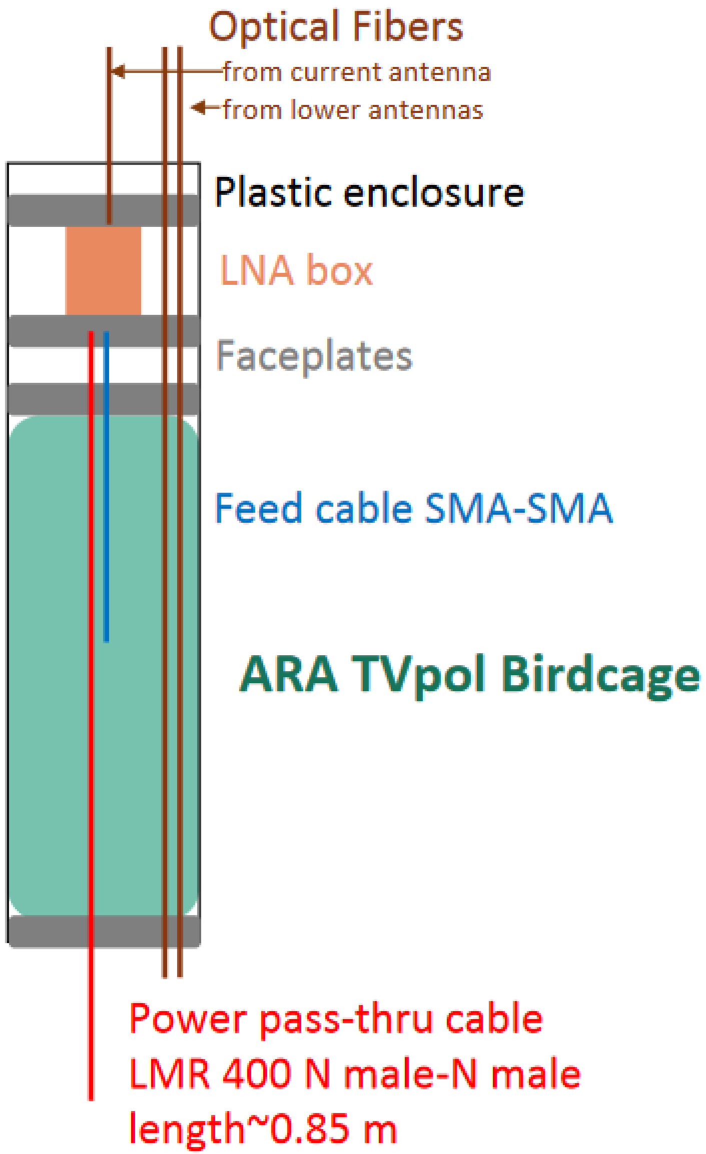
- <u>ARA approach to deep antennas</u>: LNA at antenna, coax cables run up thru higher antennas, connect to a module that sits above just above the top antenna in the hole to convert all RF channels to fiber.
- Input notch filter can be abandoned

RF front ends : integrated LNA / Optical Tx?

<u>The ARA5 phased-array approach</u>: LNA + optical Tx at each antenna, route optical fibers up through the string

Either way, we should have one front-end design that can be used for trigger and outrigger string antennas (and surface antennas, if possible, but different BW)

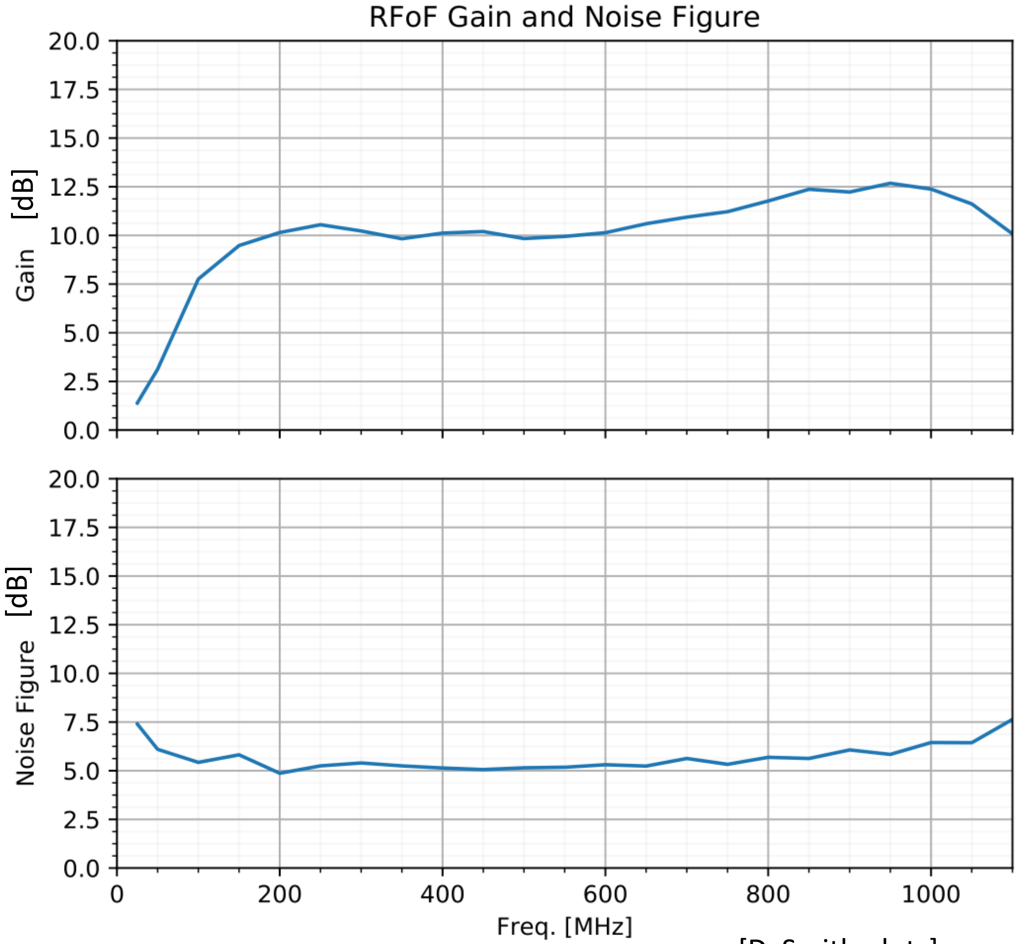
One test jig & procedure for all front-ends.



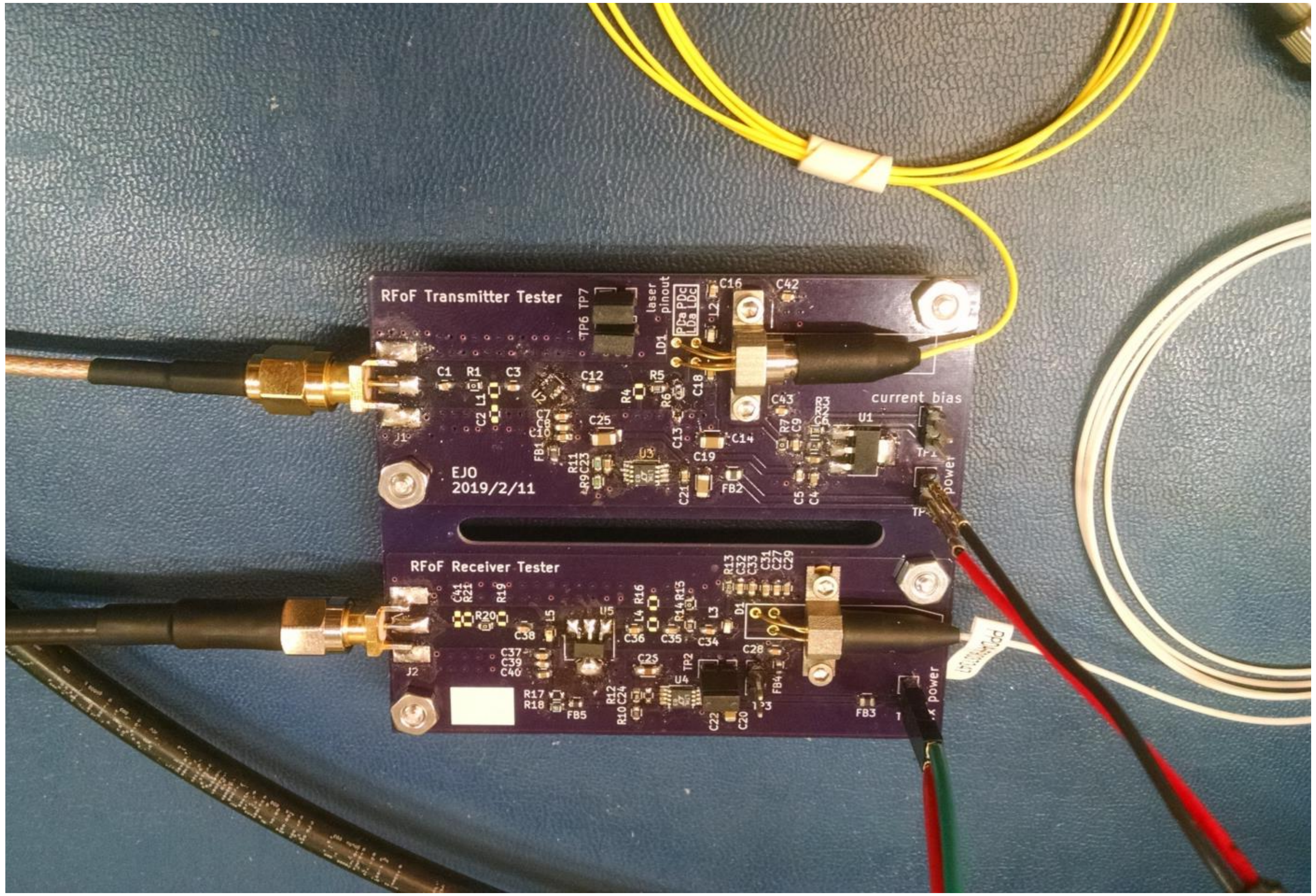
RFoF development

~$100 / link (OZ450 = $1200)
0.2-0.4W / link (OZ450 = 5 W)
10 or 30 dB link gain (OZ450 = ~20dB)

On-going optimization and performance testing. Could imagine merging the RFoF Tx and a first-stage LNA (to get NF down to 1dB) on a single-board.



[D. Smith plots]



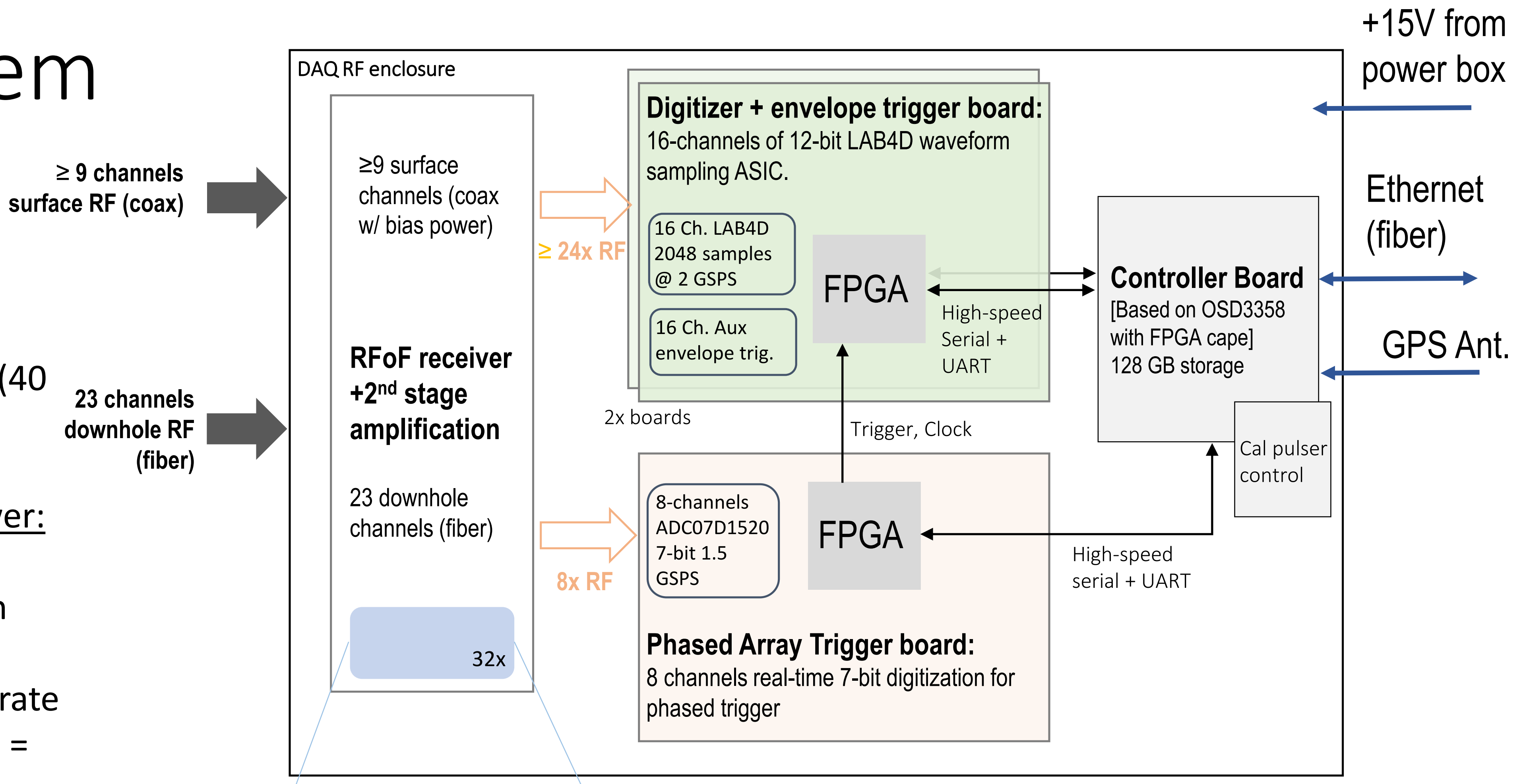
DAQ system

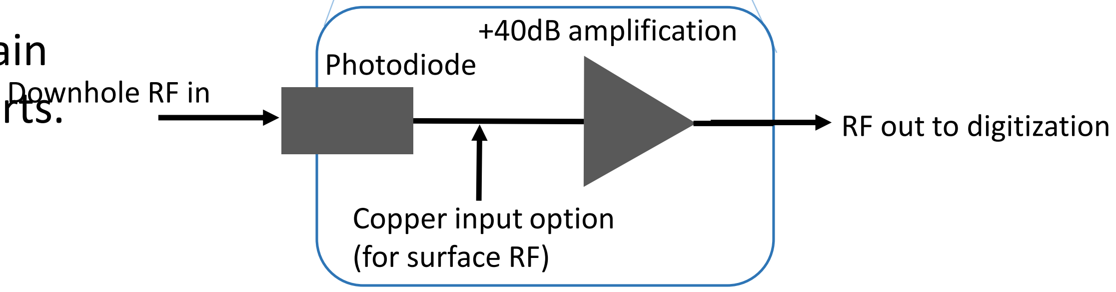
≥ 32 total Rx channels, including phased array (40 max channels)

<u>32-channel system power:</u>
~45 W for DAQ system
~60 W for entire station

~1Mbps At 10Hz event rate (mostly thermal noise!) = 2-4 TB/year/station

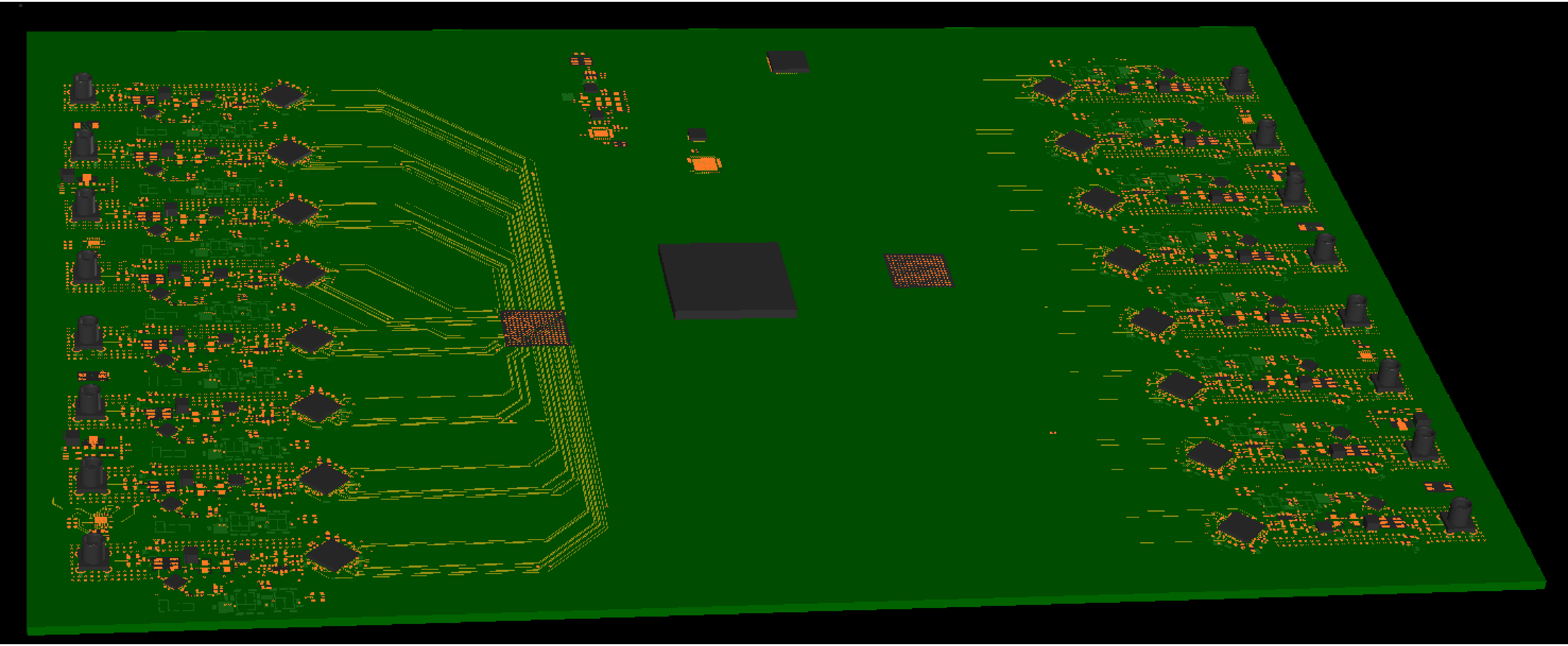
RFoF Rx and 2nd Stage gain boards will have no smarts. Quad-channel units





LAB4D digitization board

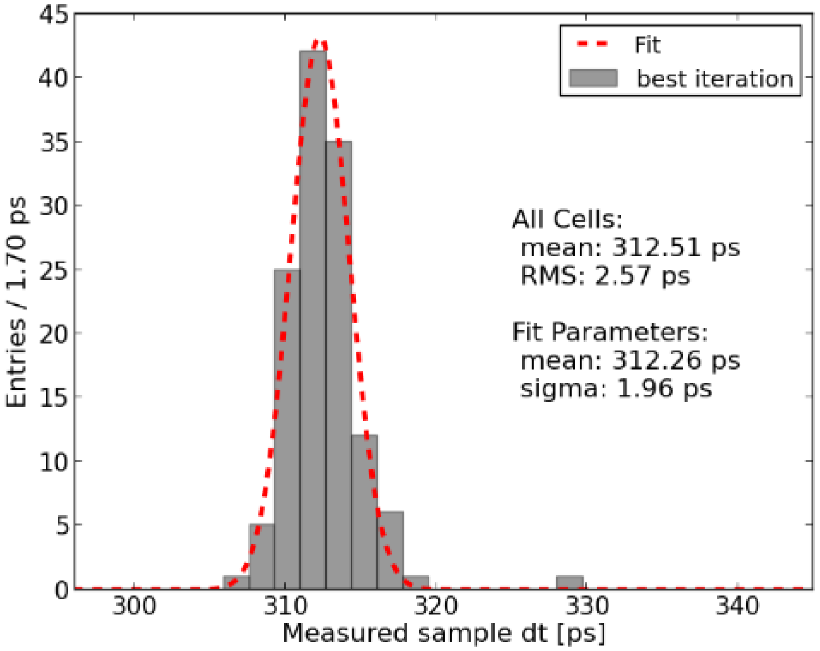
On-board waveform generation for in-situ calibration. Board will include a Schottky diode detector per channel for aux Hpol/surface trigger formation



Preliminary layout by P. Allison

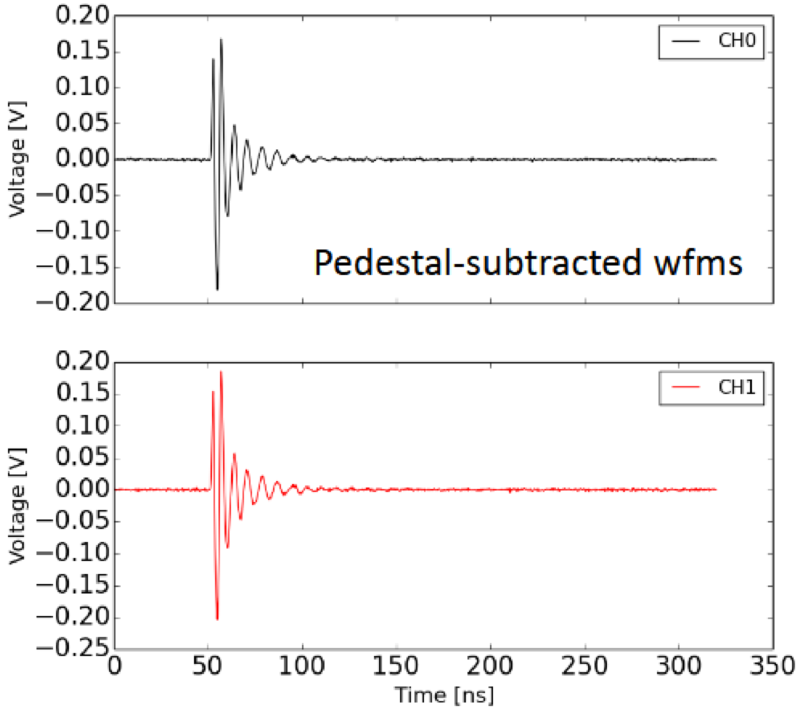
LAB4D performance

Most, if not all, of the timebase calibration is done in the chip

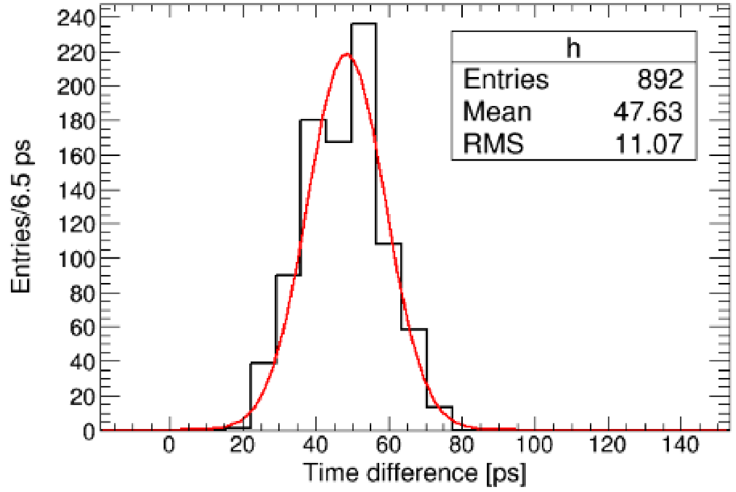


[3.2 GSa/s = 312.5 ps / sample]

Minimal off-line chip calibrations required to get science-grade performance



RMS ~11 ps without any software timing corrections (or a reference clock waveform)



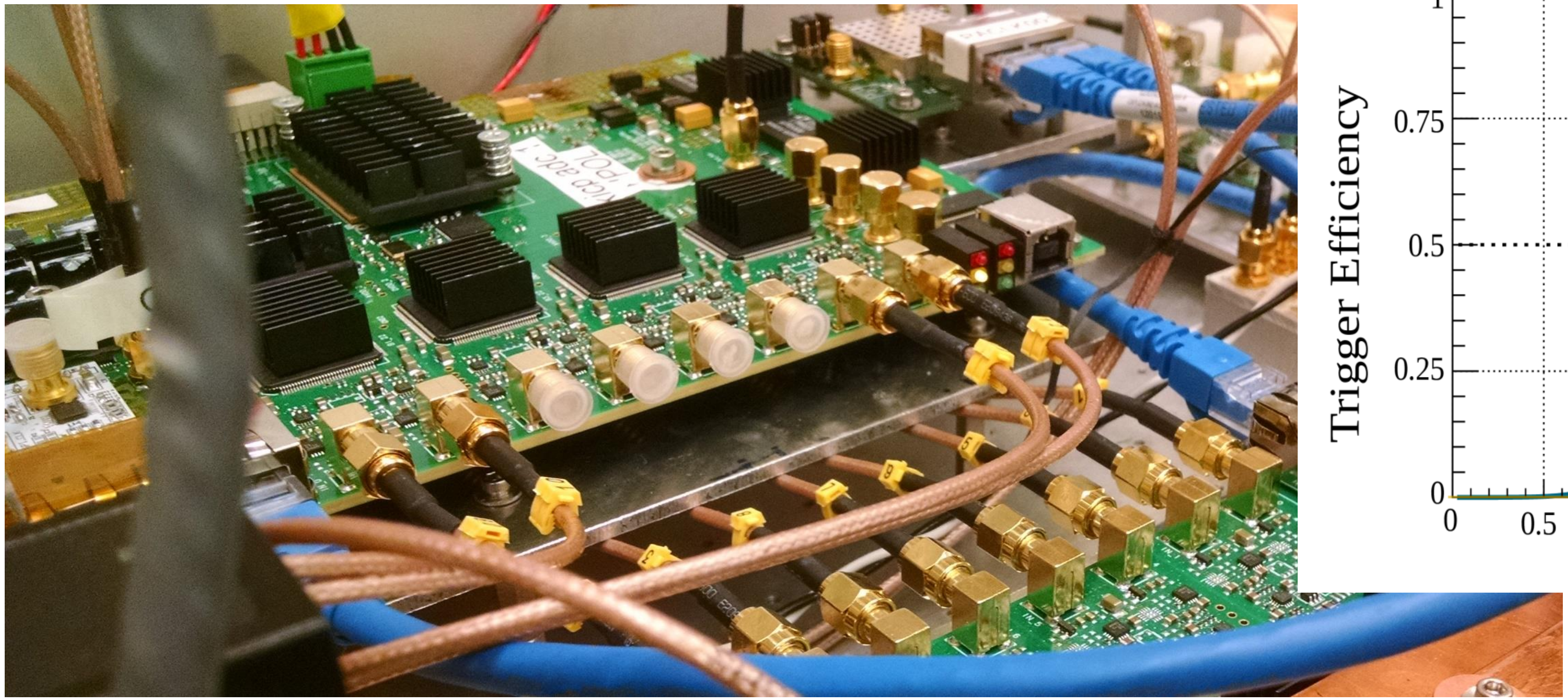
https://arxiv.org/abs/1803.04600

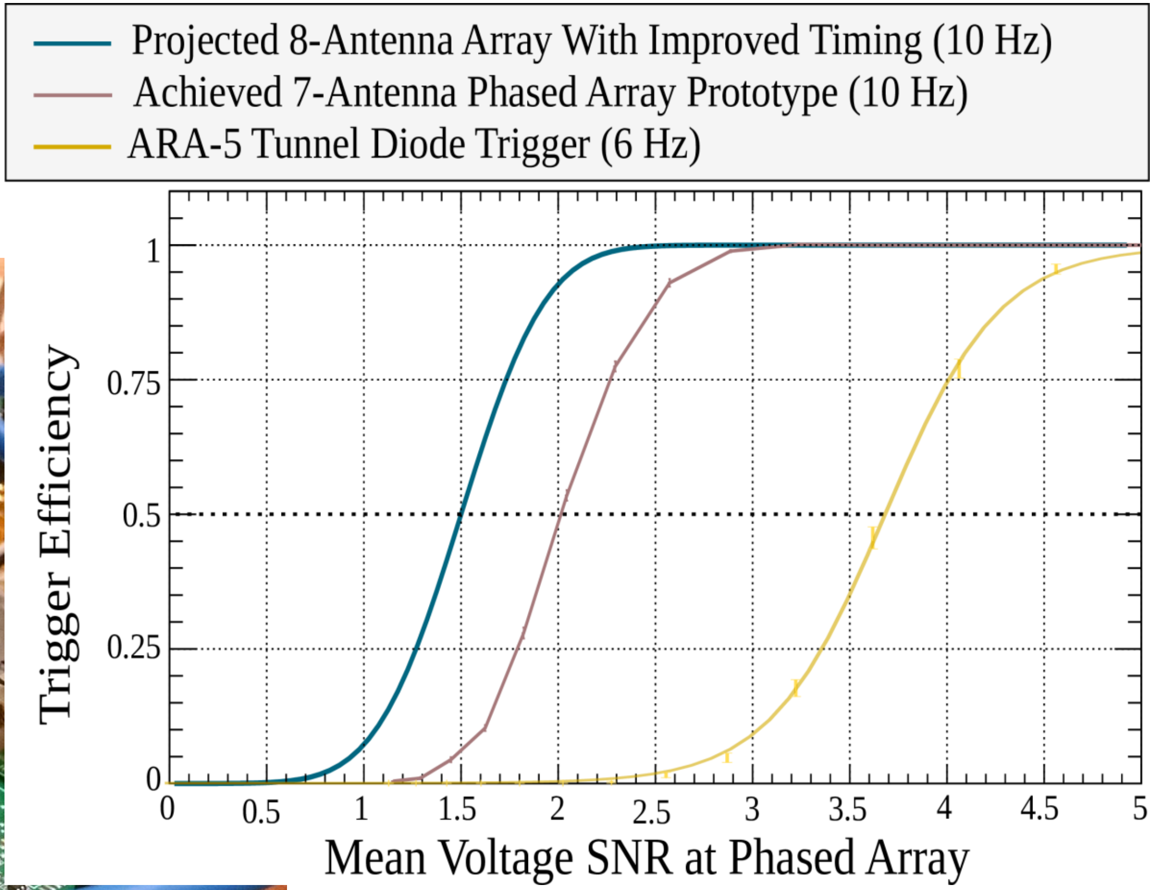
Also, in use for T-576

Phased Array trigger

Nominal plan to modify existing board for >50% power reduction, extended temp. range FPGA, adding the station master clock + a couple other small changes

Basically, turning-the-crank on a demonstrated low-threshold trigger system. 7-bit digitization gives reasonable dynamic range for use in analysis as well.





Phased Array trigger, potential (lower-power) alternatives

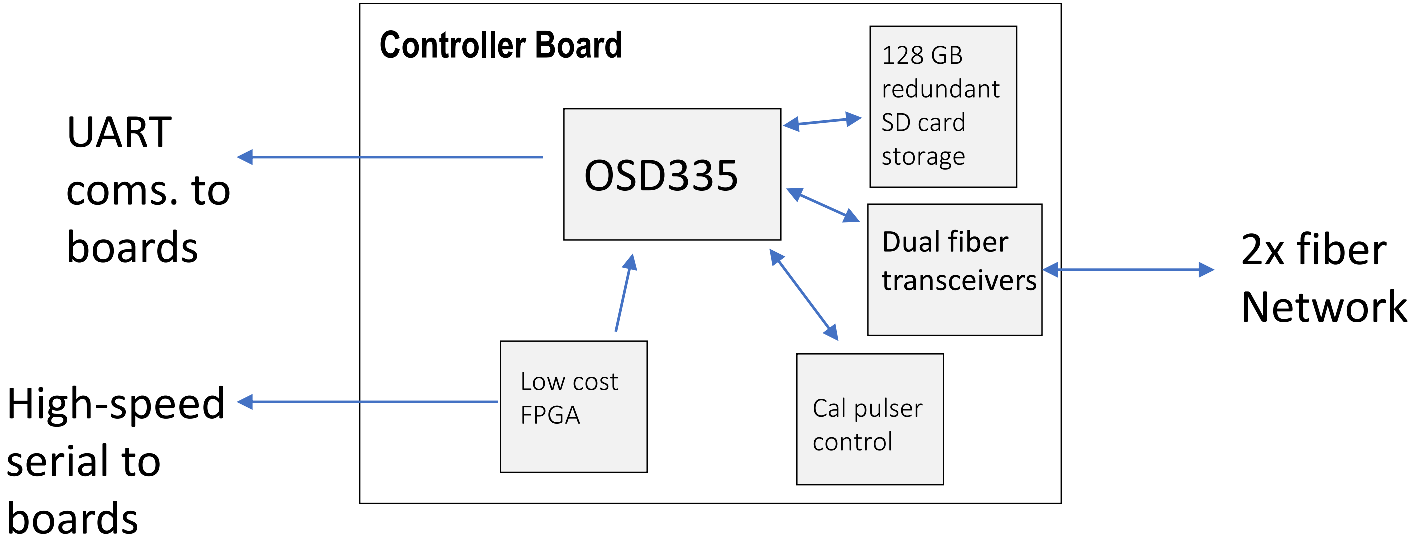
- 3-bit flash digitizer will be developed if PUEO goes forward (~0.3W/channel)
- Low-resolution digitizers being developed for SKA
- Build a ~GHz low-resolution ADC directly into an FPGA using high-speed serial receivers?

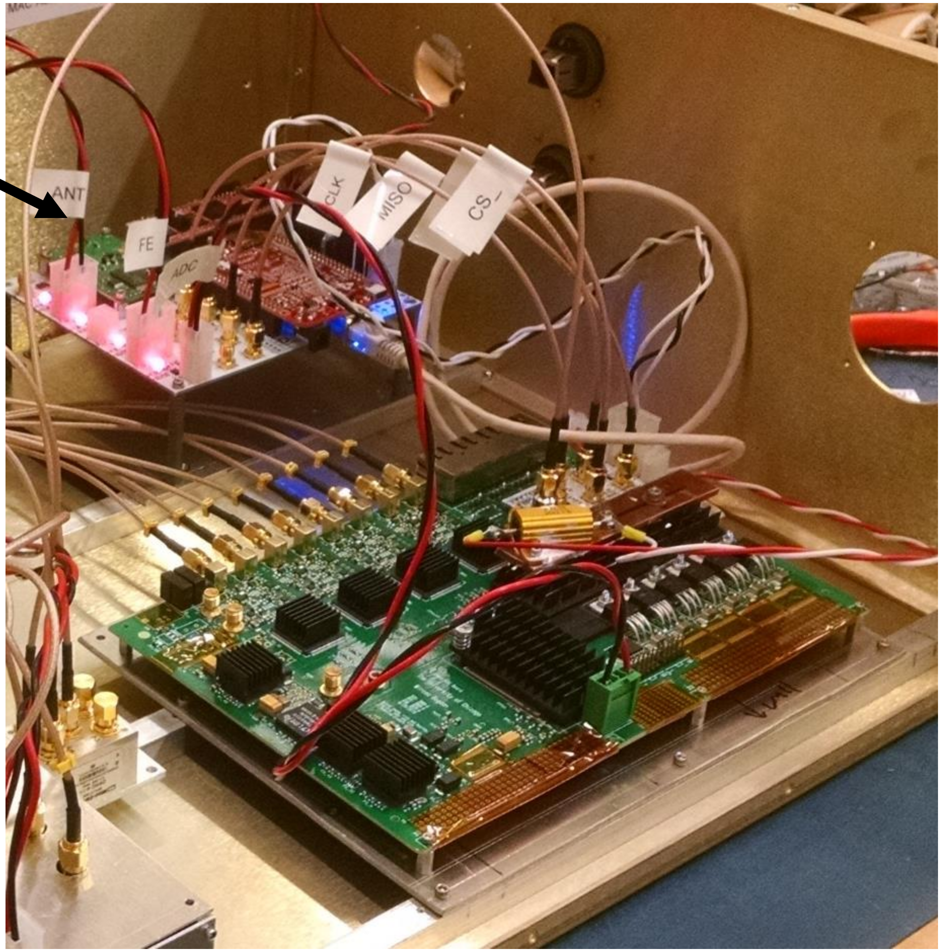
These low-resolution digitizing possibilities, along with any envelope-alignment triggers, would require splitting off signals to LAB4D channels to get reconstruction-quality data. Also, would require some level of prototyping investment for RNO.

DAQ Controller board

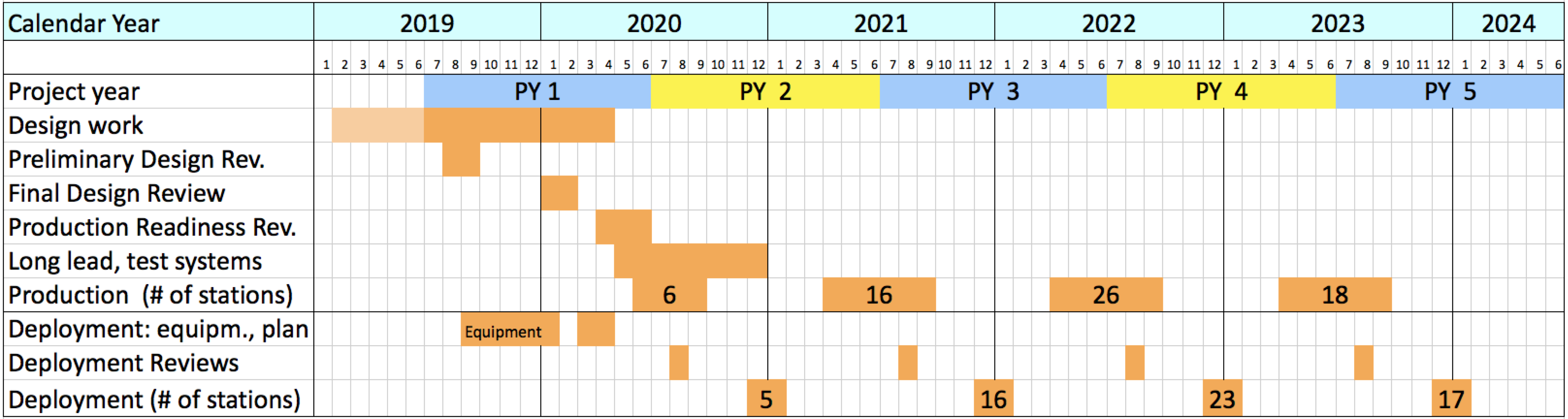
- Phased array at ARA5 has had success using the BeagleBone Black SBC ($75)+ serial links to ADC boards
- This functionality (1GHz ARM Cortex, Flash eMMC, DDR3, 2-port gigabit Ethernet MAC) is now available in an industrial-rated system-in-package: OSD335x

  --> Put all of the station control into a single board. Simplified and streamlined





Schedule



- We need to ramp up production work ASAP if 2020-21 deployment is happening.
- Plan to start up a standing RNO hardware call time in next couple weeks

RNO Subsystem to-do:

1) Antennas + RF front-ends

- Is there a path towards large scale production of ARA-like antennas?
  - To what degree are new/modified antenna designs needed?
  - Calibration plan is important – polarization response key to reconstruction. Should have full system response on each channel before shipping
- Decide on a RF front-end architecture
  - Enclosure + LNA design + test-jig
- We should be running the front-ends with no more than 5V (3-3.3V is even better!)
  - ARA is running downhole RF front-ends at 12V, due to commercial RFoF power requirements. Burning a ton of heat in regulator drop-out.
  - The prototype UChicago RFoF Tx will run at 3V. So far so good with this development, pending low-temp tests

RNO Subsystem to-do:
2) RF Signal / power transport

- This is basically just cabling
- The downhole signal/power transport will depend on the RF-front end architecture choice
- Will still need a ‘DTM’-like module at the top of each deep string to include a power-regulation stage + cable conversion
- Phased array timing mismatches primarily come from fiber-length differences within the tactical bundle -

RNO Subsystem to-do:
3) DAQ

- DAQ enclosure design
- Board designs:
  - 2nd stage signal conditioning (quad channel) + enclosures + test jigs
  - 16-channel LAB4D digitizing board – design underway
  - Phased-array trigger board – nominal design close to current
  - Controller board
- Good amount of code and test-stand development needed.
  - Good news is that the firmware for PA trigger and LAB4D digitizer control/readout well established.
- Proper EMI testing

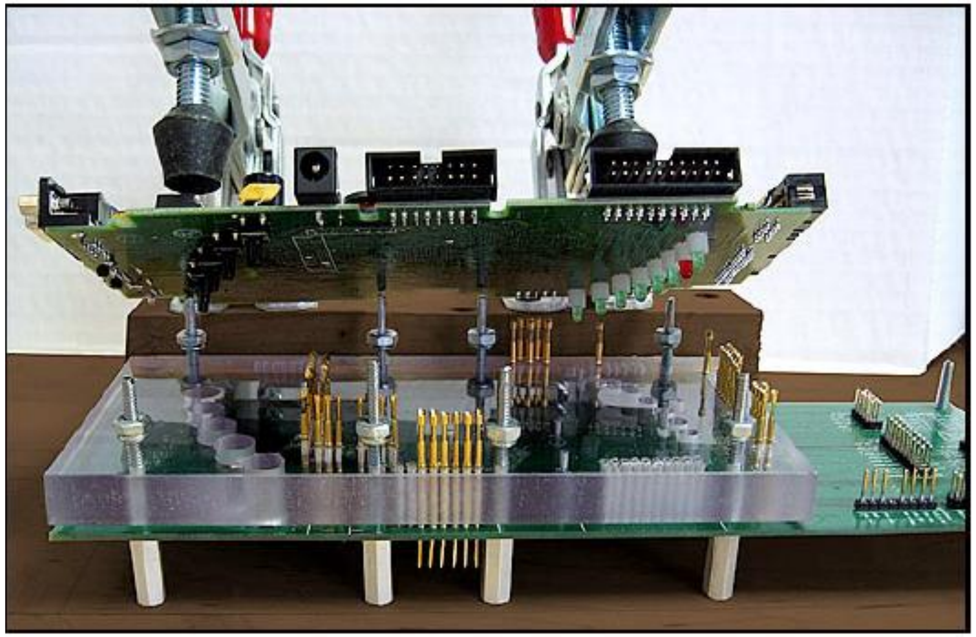
RNO Subsystem to-do:
4) Calibration Tx

- Will have to be at least somewhat different than ARA to accommodate location in middle of string

RNO Subsystem to-do:
5) Station Power & Coms.

- Similar to ARA, a HV->15V DC-DC converter will live in a separate box
  - Proper EMI testing required
  - ARA currently uses 250W Vicors, should be able to redesign with ~125W converters without issue.
- A lot will depend on the power/network grid infrastructure decisions

Prototype vs production



[slide from P. Allison, from DAQ meeting discussions at UCIrvine 2018]

Example: amplifier testing

- Prototype amp testing: ~1 person-hour/station
  - Connect VNA to input, output, power (1-2 minutes)
  - Start testing script (current measurement, frequency sweep, current sweep), entering unique ID for amplifier (1-2 minutes)
  - Disconnect, store tested amp when complete, fetch new amp (1-2 minutes)
  - For 32+ channels per station, this becomes significant: on the order of 1 person-hour
  - For *production* (O(100)) also have other concerns
    - VNA, power need a sacrificial connector (SMAs don't have 3000+ insert/remove cycles)
    - Calibration drift over time, etc.
- Production amp testing: ~2 person-*min*/station
  - Grab 4 boards from batch, place on jig and push down to secure. Jig autodetects presence of boards.
  - Replace with new batch when jig indicates test finished
  - Easily can reach 32 channels in under 2 minutes of person-time

[not including burn-in / temperature / etc]