Racks, A Comfortable Home for LCLS-II LLRF

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Abstract

A superconducting CW RF linear accelerator is being built at the SLAC National Accelerator Laboratory to provide 4 GeV short bunch-length electrons to LCLS-II undulators at high repetition rate. LCLS-II RF requirements have driven the need for a high precision RF control system (Emma & et al., 2014). A digital LLRF system was designed by a multi-lab collaboration to meet the LLRF needs of LCLS-II (C.Hovater & et al., 2015). Results from initial testing have demonstrated that the system meets and exceeds critical performance requirements (Doolittle & et al., 2017) enabling low phase noise control of superconducting cryomodules as well as the possibility of active compensation for microphonics. The modern, high performance LLRF system will be distributed in the first kilometer of the SLAC klystron gallery, a non-air conditioned structure with well documented ambient temperature stability limitations (Akre & et al., 1997); the klystron gallery can vary 50 degrees F in a single day. To overcome the thermal stability limitations of the klystron gallery, a rack system has been carefully, yet cost effectively, designed to house the distributed LLRF system. The LLRF racks have been strategically placed close to accelerator penetrations to minimize effects from temperature drift on long haul RF cables. Careful attention has also been paid to the internal design of the rack to keep temperature sensitive LLRF chassis thermally stable and microphonics sensitive chassis acoustically stable. The LLRF rack design considerations will be presented with test results demonstrating a variety of metrics including temperature, acoustic, and RF stability.

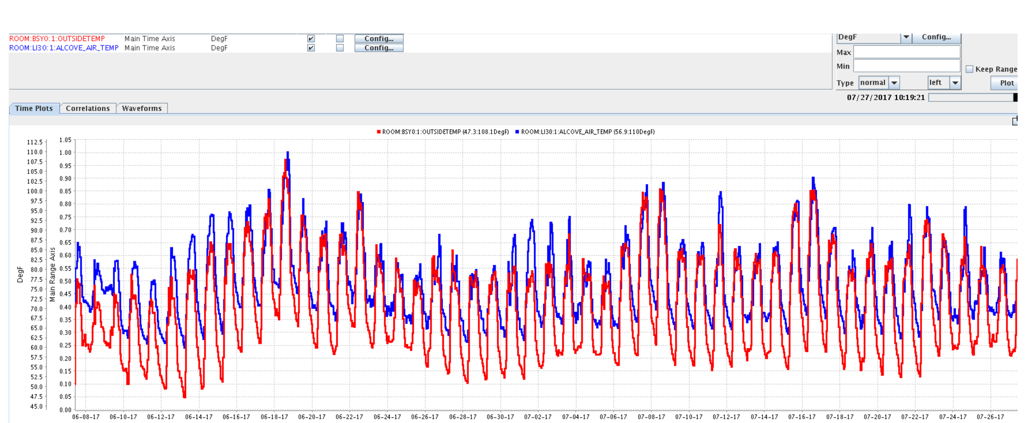
Emma, P., & et al. (2014). Linear Accelerator Design for the LCLS-II FEL Facility. *Proceedings of FEL2014.* Basel.
C.Hovater. (2015). The LCLS-II LLRF System. *Proceedings of IPAC2015.* Richmond.
Doolittle, L., & et al. (2017). High Precision RF Control For SRF Cavities in LCLS-II. *SRF 2017.* Lanzhou.
Akre, R. (1997). SLC Interferometer Systems and Phase Distribution Upgrades. *PAC.* Vancouver.

The Two Mile Shed

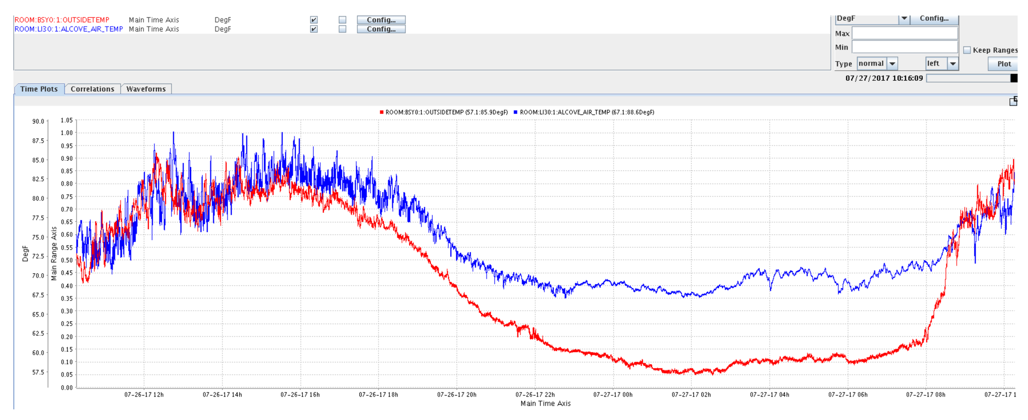
"The sun coming up in the morning on a beautiful sunny day for someone in Stanford, California is not such a nice experience if one is an operator of the Stanford Linear Collider (SLC) trying to maintain luminosity. The improvements on the SLC the past decade have decreased the emittance of the beam to a point where the existing phase variations in the RF, due to diurnal temperature changes, significantly affect luminosity. The effects are greatest at sunrise when the temperature gradient with respect to time is the largest." Ron Aker 1997

Temperature Stability

- Red = outside gallery deg F – 50 to 105 deg F
- Blue = inside gallery deg F – 60 to 110 deg F

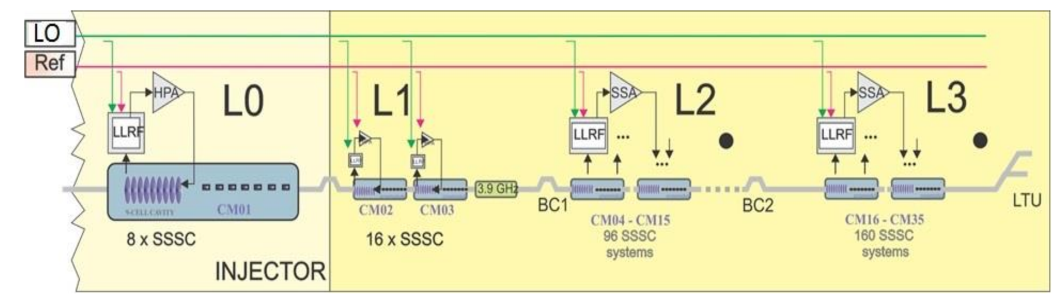


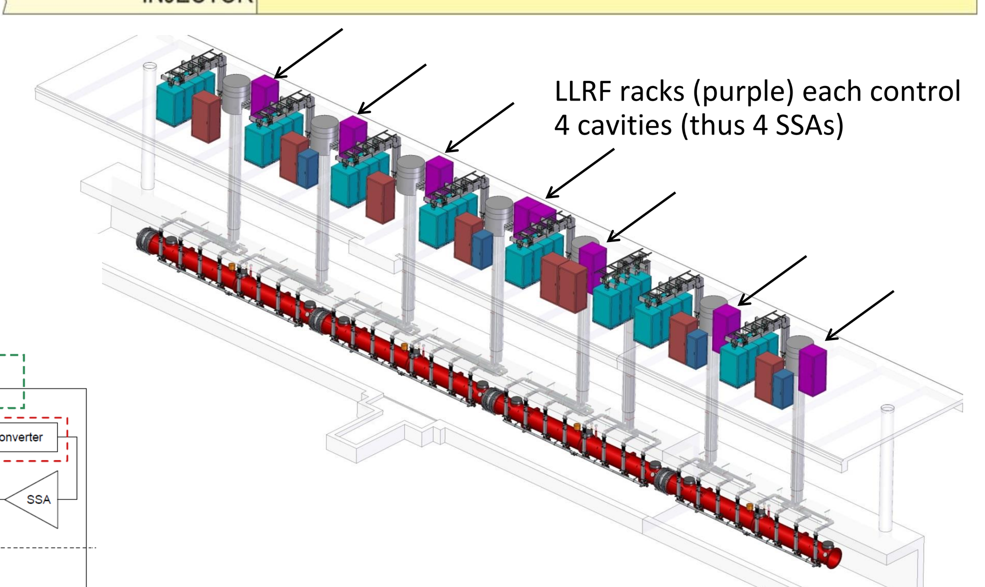
- Red = outside gallery deg F – 58 to 85 deg F
- Blue = inside gallery deg F – 70 to 90 deg F
- Inside gallery dT/dt ~ 5 deg/ hour



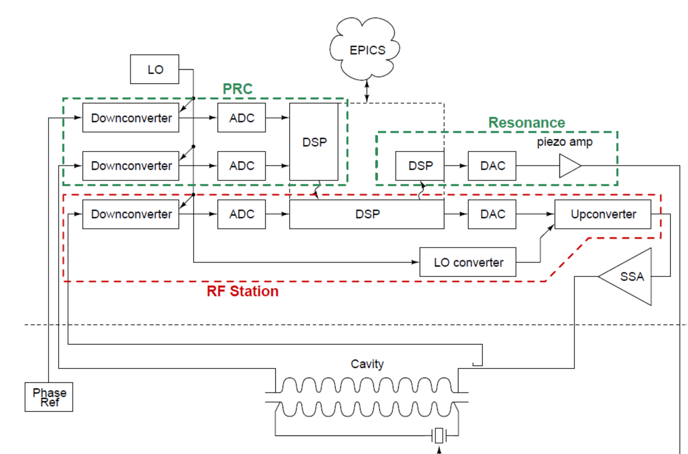
LCLS – II LLRF & Rack System Requirements and Design

- LCLS – II is composed of 35 superconducting cryomodules each with eight 1.3 GHz
- Single Source Single Cavity architecture chose for precision field control in CW mode operation
- One 186 MHz RF Gun – 1 normal conducting cavity with 2 SSAs and 2 RF controllers
- One 1300 MHz Buncher – 2 normal conducting cavities with 4 SSAs and 4 RF controllers
- 280 1300 MHz Superconducting Cavities each with 1 SSA and 1 RF Controller
- 16 3.9 GHz Superconducting Cavities each with 1 SSA and 1 RF Controller
- 76 total LLRF racks, each rack contains entire field control system for 4 superconducting cavities (half cryomodule)



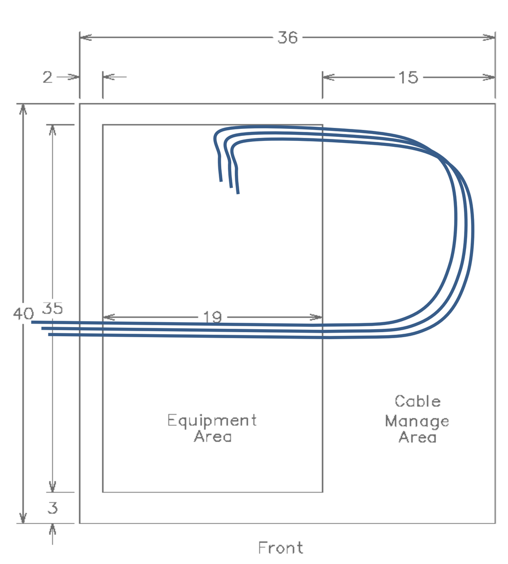


- General Rack area is temperature controlled to +/- 5C
- PRC Area Temperature controlled to +/- 2C
- Racks can not exceed 35 C
- Rack Components
  - Network patch hardware
  - LO and RF Signals
  - 2 RF Stations (RFS)
  - Resonance Control
  - Power Supply
  - Cavity/Cryomodule Interlocks
  - Terminal Blocks
  - Precision Receiver Chassis (PRC)

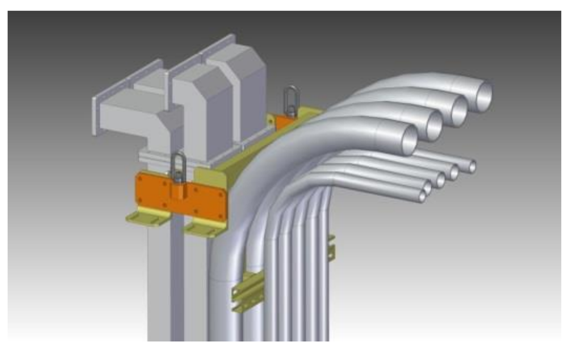


Cable management

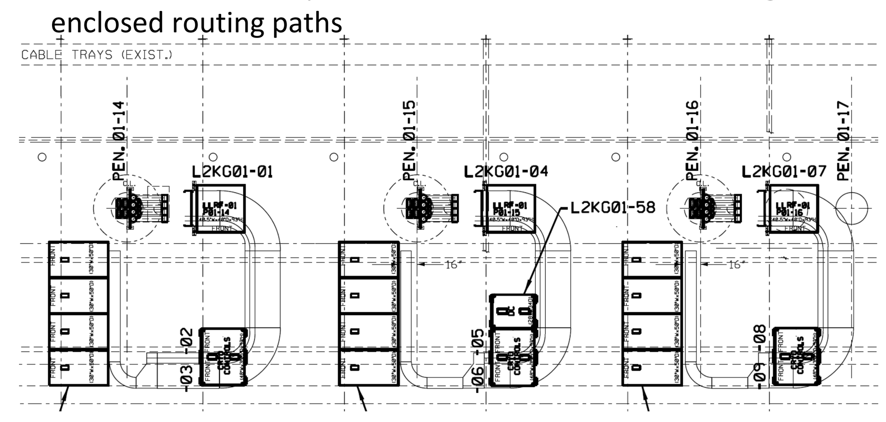
- **22 long haul 3/8" heliax cables entering rack**
- **Cables connected directly to LLRF chassis – no patch**
- **Minimum multiple bend radius (multiple) = 3.75"**
- **Don't forget space for attenuators as needed in back of chassis**
- **Heliax cable strain relief will be built into rack rails at back of each chassis**

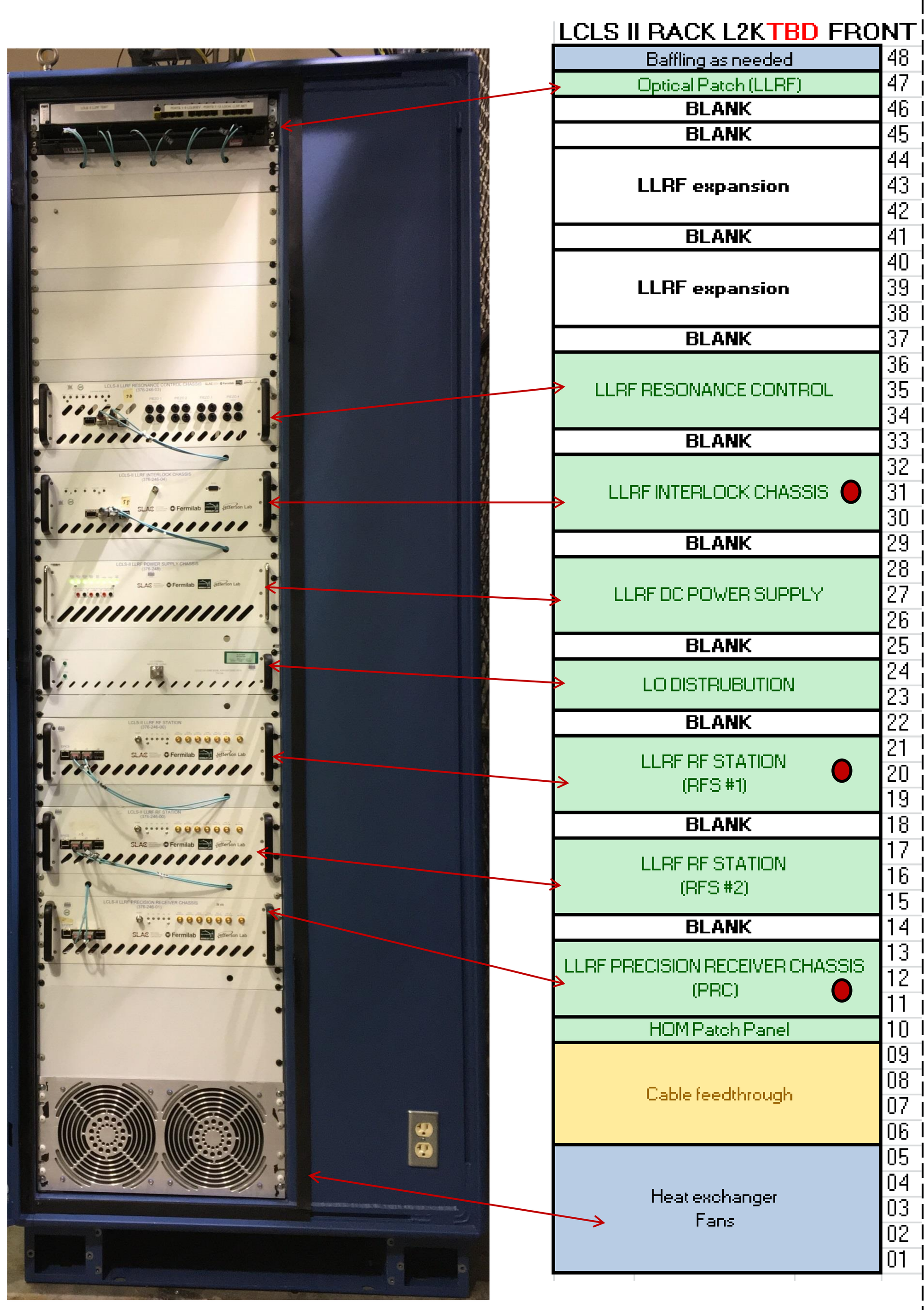


- **To minimize the effect of thermal drift on signal cables, RF heliax will enter side of LLRF rack as close as possible to accelerator housing penetration.**
- **Gap between penetrations and rack is ~ 3 ft.**



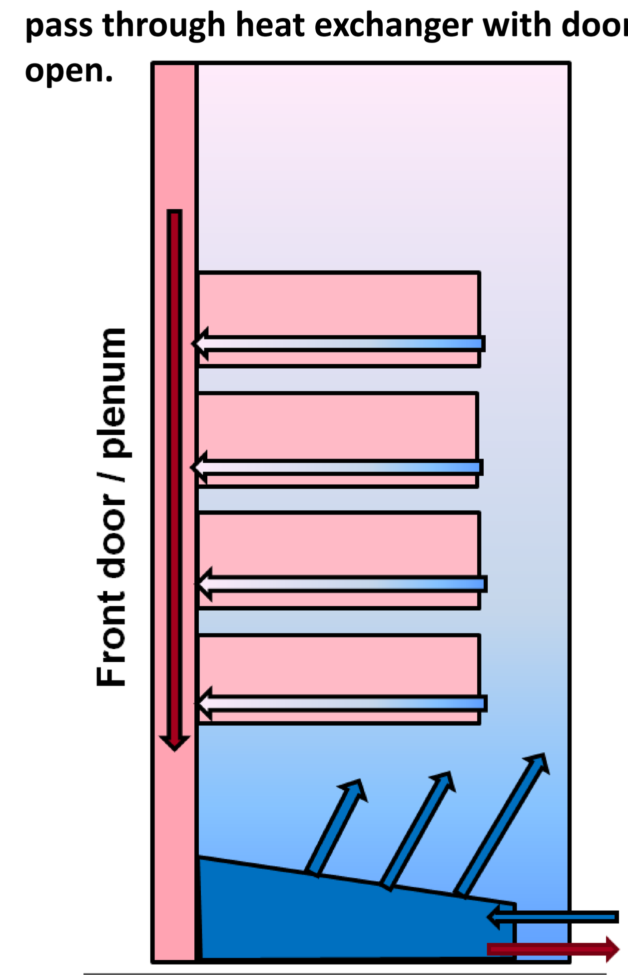
Feedback cable temperature extremes minimized through short enclosed routing paths

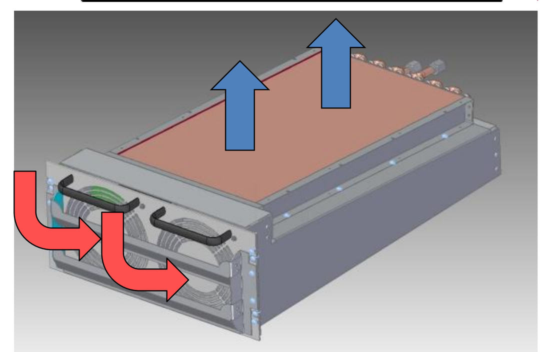




Air to water heat exchanger design

- **Heat exchanger has large surface area ($2\ ft^2$) to help maintain temperature lock with water**
- **Water system speced for 4 GPM to LLRF racks @ 30 deg C ± 0.5 deg**
- **Heat exchanger rated to 150 PSI**
  - **40 PSI = 3.6 GPM flow of water**
- **Two 110 VAC fans push air into rear plenum, chassis air receives at least one pass through heat exchanger with door open.**

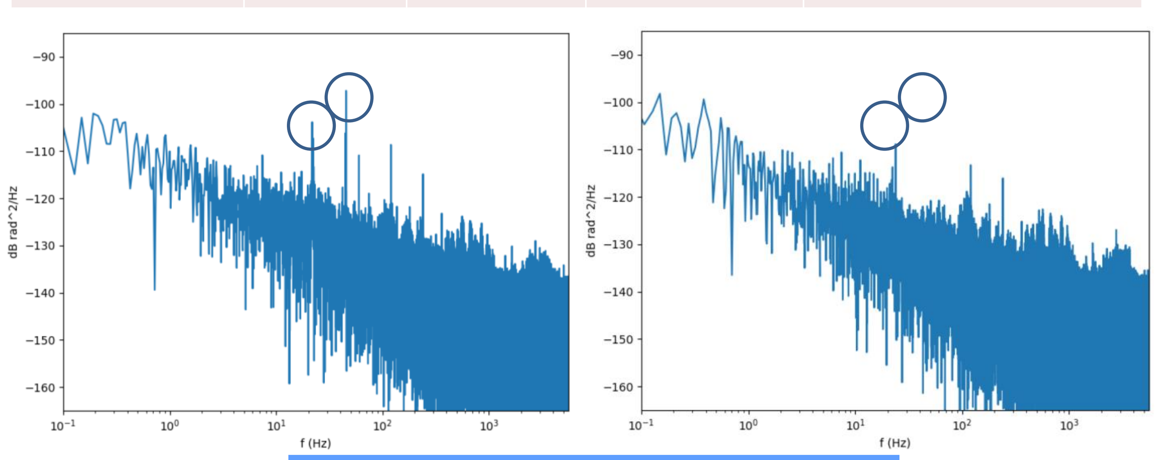




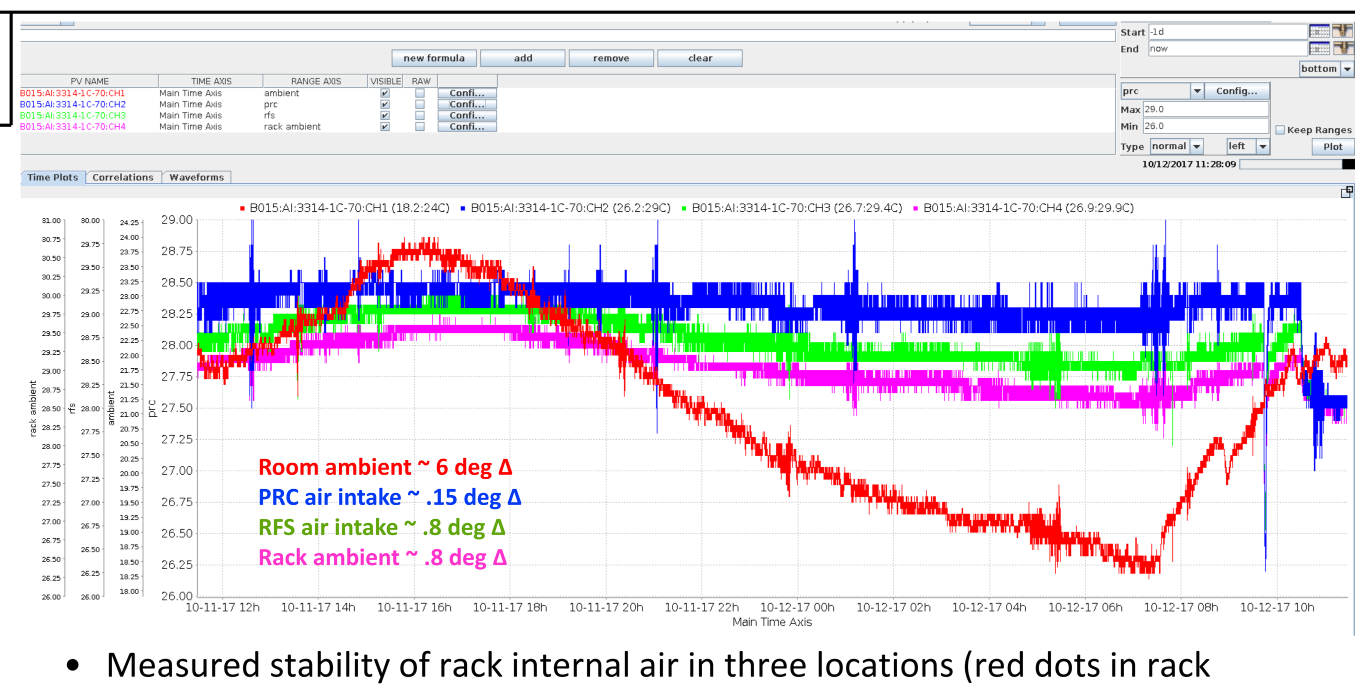
Measured Performance

- **Rack fan assembly recently optimized for improved air flow ~ 90%**
- **Study made to determine if lower fan speed (less audible noise) is preferable to increased air flow**
- **Variac used to adjust fan speed to affect audible noise and air speed**

Fan setting	Chassis	Air speed (Lf/m)	Audible noise (dB)	Phase stability (mdeg)
High 110 V_{rms}	PRC	820	90	0.477
	RFS	830	89	
Low 70 V_{RMS}	PRC	480	72	0.407
	RFS	450	71	



Observable acoustic noise at high fan speed



- Measured stability of rack internal air in three locations (red dots in rack profile) over 24 hour period and compared to room ambient air
- PRC observed .026 °C/°C (chassis air to external ambient air) variation in temperature
  - Rack specification written for 4 – 40 °C ambient will result in 0.94 °C shift in PRC temperature
- Opened front door for 2 minutes, observed 2 °C sudden drop in PRC air temperature – need to minimize rack access
- Adjusted water 1 °C cooler, observed quick response of PRC air temperature – PRC is closely locked to water temperature
- Rack average temperature observed 0.14 °C/°C (rack ambient to room ambient) variation in temperature

Summary

- ✓ **PRC Area Temperature Maximum and Tolerance: 35 Degree C Max with stability of +/-2 Degree C**
- ✓ **RF Station/Resonance/Interlocks/ Area Max Temperature with Tolerance: 35 Degree C max +/-5 Degree C (note can have temperature gradient from bottom to top of 10C max)**
- ✓ **Rack heat load from LLRF: Total 250 Watts (PRC area 35 Watts)**
  - **350 W total with running stepper motors and fan assembly (large flywheel)**
- ❑ **Acoustic Noise: 60 dBA max**
- ✓ **Electrical Service: Two 20A breakers each with power strips**
- ✓ **AC outlet at the bottom of the rack (front and rear) for test equipment.**
- ✓ **Fiber Patch Panel Near the top of the rack**
- ✓ **Max cable length for quantity 6, 3/8 inch heliax from penetration opening to inside of LLRF rack is approximately 30 feet. The cables should enter the rack from sides near the base of the rack.**

Acknowledgements

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