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Low Level RF Control System

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PIP-II Machine Advisory Committee

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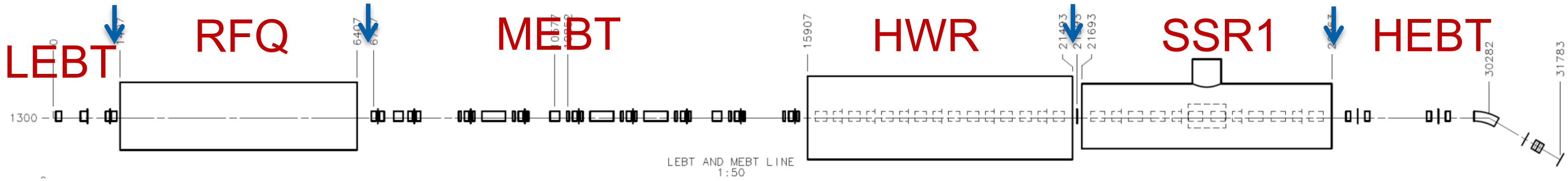
Outline

- R&D Scope and plans
- Requirements
- Collaborations
  - India
  - Colorado State University
  - Berkeley (maybe)
- Current system development
  - Master Oscillator and Reference line
  - Controller module
    - System on module
- Conclusions

PXIE Low Level RF Group Involvement

Now — 2015 — 2016 — 2017 → 2018

30 keV   2.1 MeV   10 MeV   25 MeV



← 40 m, ~25 MeV →

PXIE will address the address/measure the following:

- LEBT pre-chopping
- Vacuum management in the LEBT/RFQ region
- Validation of chopper performance
- Bunch extinction
- MEBT beam absorber
- MEBT vacuum management
- Operation of HWR in close proximity to 10 kW absorber
- Operation of SSR with beam, including resonance control and LFD compensation in pulsed operations
- Emittance preservation and beam halo formation through the front end

Collaborators
- ANL: HWR
- LBNL:LEBT, RFQ
- SNS: LEBT
- BARC: MEBT, SSR1

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R&D Deliverables

Deliverable	Date
Reference Design Report	Q1FY15
HB650 Cavity (8, TESLA shape) Vertical Test (US)	Q4FY15
HB650 Dressed Cavity (3) Horizontal Test (US)	Q4FY16
HB650 Dressed Cavity (4) Horizontal Test (India)	Q2FY17
LB650 Dressed Cavity (3) Horizontal Test (US)	Q3FY17
LB650 Dressed Cavity (2) Horizontal Test (India)	Q3FY17
HB650 Cryomodule Design (US, India)	Q2FY16
HB650 Cryomodule Power Test (US)	Q4FY17
650 MHz/30 kW rf Power Test (India)	Q4FY15
SSR1 Dressed Cavity (2) Horizontal Test (India)	Q4FY15
SSR1 Cryomodule Power Test (U.S.)	Q3FY17
SSR2 Dressed Cavity (2) Horizontal Test (India)	Q2FY17
SSR2 Cavity (2) Vertical Test (US)	Q4FY17
SSR2 Dressed Cavity (1) Horizontal Test (US)	Q4FY17
325 MHz/10 kW rf Power Test (India)	Q4FY15
650 MHz Horizontal Test Stand (US & India)	Q3FY16
HWR Cryomodule Test with Beam	Q2FY18
Front End Systems Test (warm components)	Q3FY16

LLRF Systems needed to meet R&D Goals

- 325 MHz Horizontal test stand
  - Support for CW and pulsed mode operation
  - Operational now with some upgrades planed
- 650 MHz Horizontal test stand
  - Support for CW and pulsed mode operation
  - Supplied by India Q3FY16
- PXIE
  - Master Oscillator and Phase Reference distribution line
    - 162.5 MHz & 325 MHz (In construction phase)
  - RFQ – 162.5 MHz (Q4FY15)
    - 2 RF amplifier system
  - Buncher - 3 cavities - 162.5 MHz (FY15)
  - Half Wave Resonators - 8 cavities @162.5 MHz (FY17)
  - SSR1 - 8 cavities @ 325 MHz (FY17)
  - Kicker waveform generator

Collaboration with India on LLRF

- The plan
  - Colleagues from BARC will develop the 650 MHz test stand including LLRF
  - They will deliver 50% of the LLRF systems in PIP-II
  - They will send a LLRF engineer to work with our team for two years
- Final systems must be hardware, firmware and software compatible to avoid operational risk
  - this probably means identical systems in the end
- The “how to” for this collaboration effort needs development
  - common development platforms are a must

Collaboration with other labs

- We are involved in the LCLS-II LLRF design effort as well as testing of cavities at CMTF
- We hope to leverage off of this effort and possibly collaborate with this same group for PIP-II

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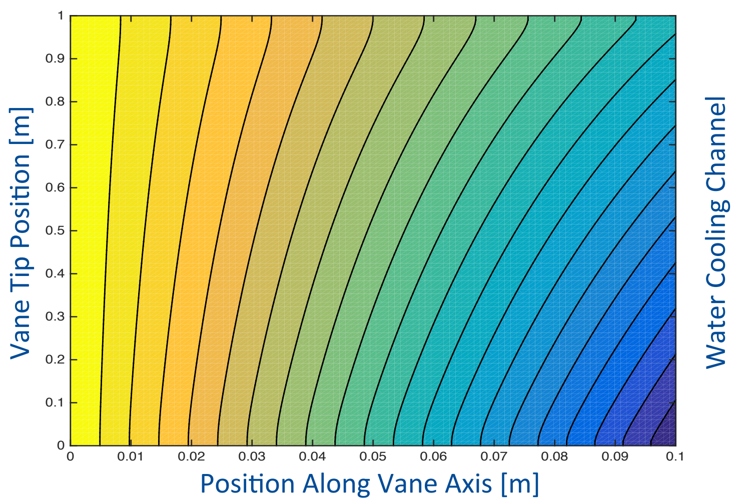
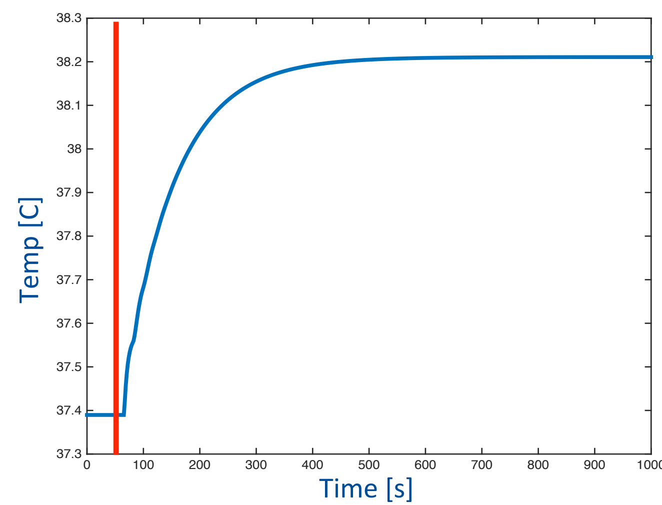
Resonance Control Effort for the PXIE RFQ

- Tuning controlled by adjusting the vane and wall temperatures
- Initial focus is on temperature control of the water at the entrance of the RFQ
  - Began modeling the thermal properties of the RFQ (including RF heating) and the dynamics of the water cooling system
  - Conducting initial control studies to ensure that the system response requirements can be met for trip recovery, cold starts, and both CW and pulsed operation
- Will later re-focus efforts on LLRF and resonance control
  - Dynamic tuning by adjusting the vane temperature
  - Low duty pulsed operation: vary the RF pulse width to adjust vane heating
  - Resonance controller to interface with water system
- The full team led by Jim Steimel: *Curtis Baffes, Maurice Ball, Sandra Biedron*, Daniel Bowring, Brian Chase, Jerzy Czajkowski, Auralee Edelen*, Jonathan Edelen*, Stephen Milton**

**Colorado State University contract*

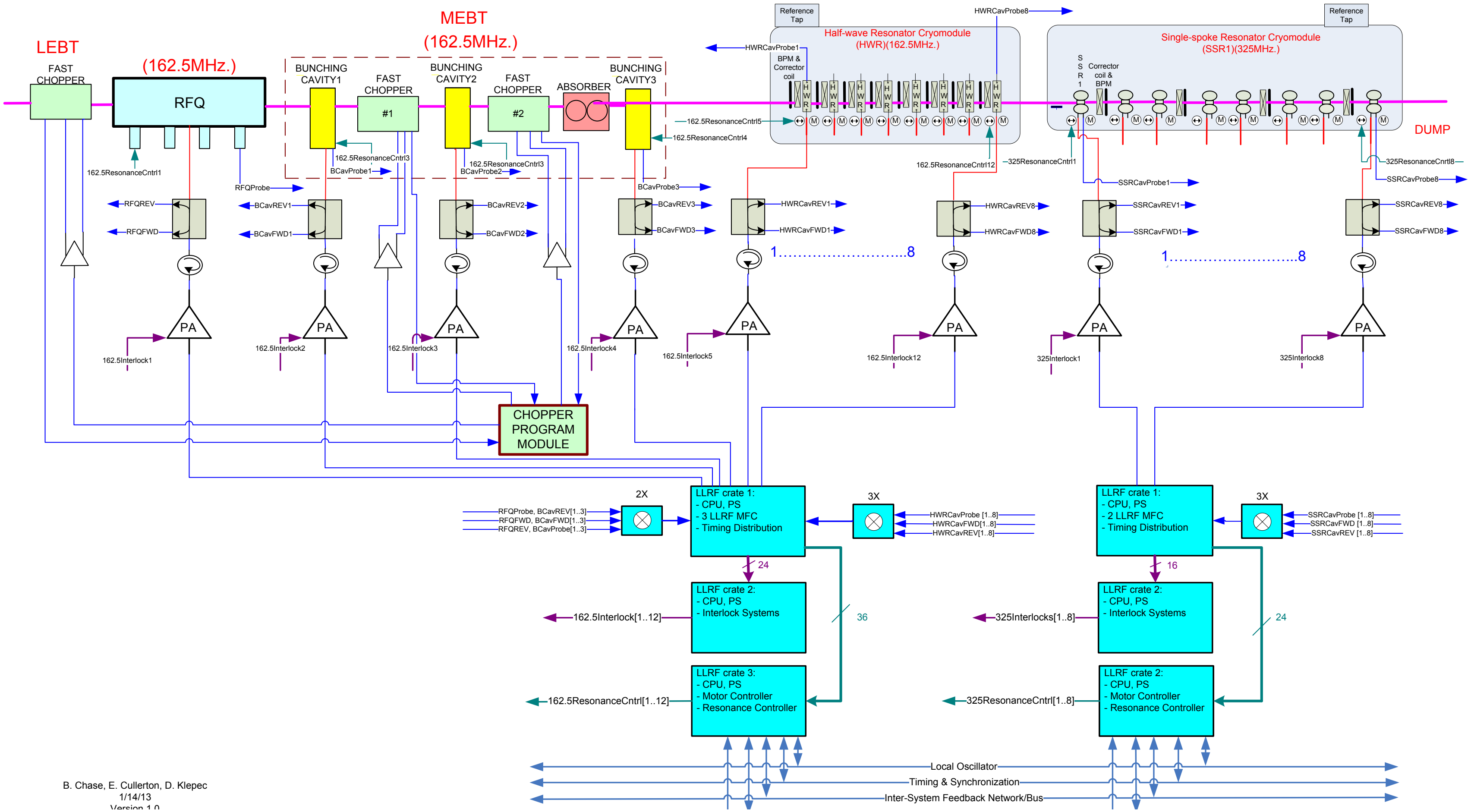


2-D thermal simulation of temperature gradient induced in the vane due to the temperature rise of the water in the cooling channel



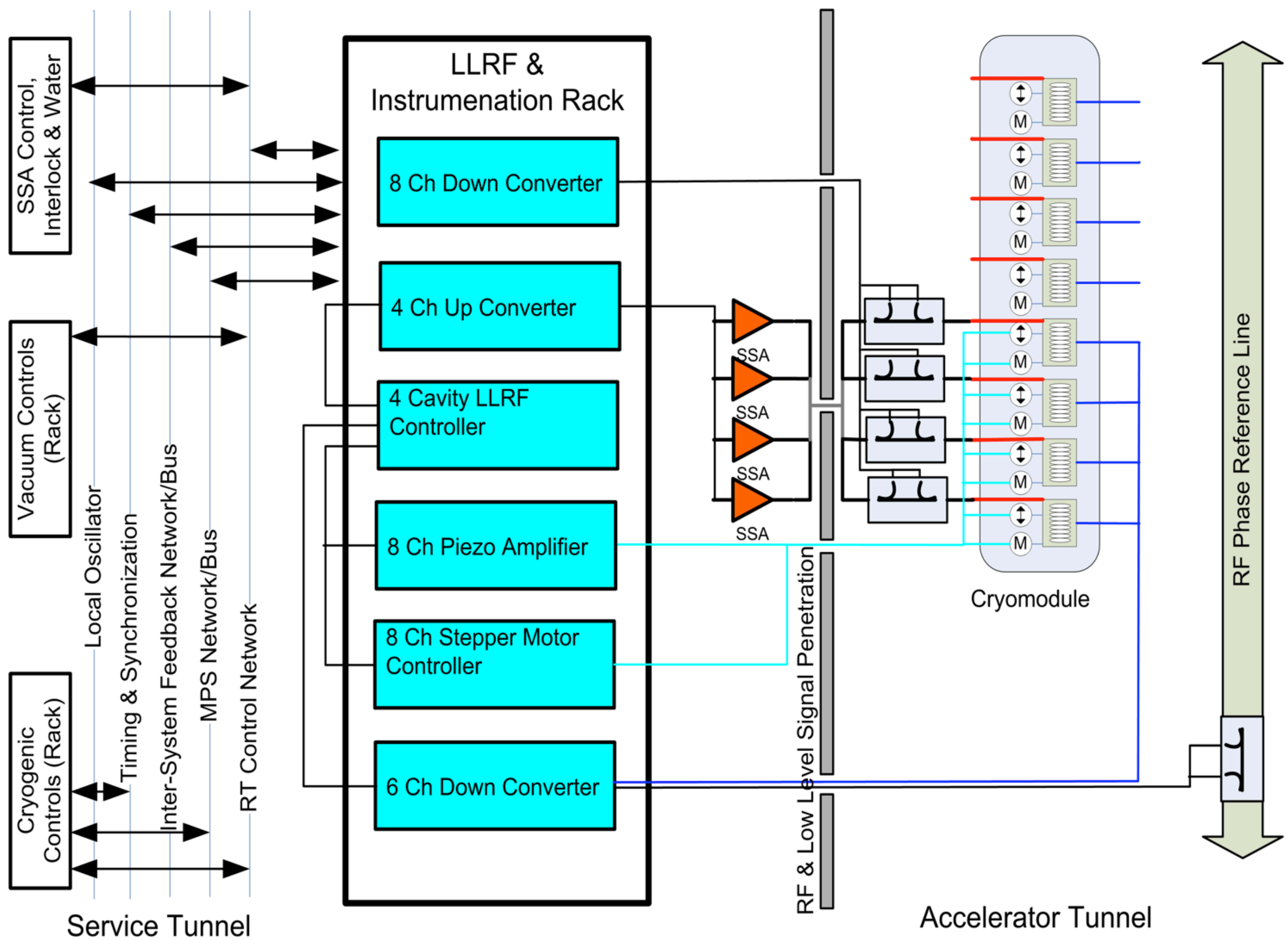
Uncompensated temperature at the entrance to the RFQ as a function of time after a step change in the cold water control valve (occurs at t=50 as indicated by the red line)

PIXIE RF Stations Diagram



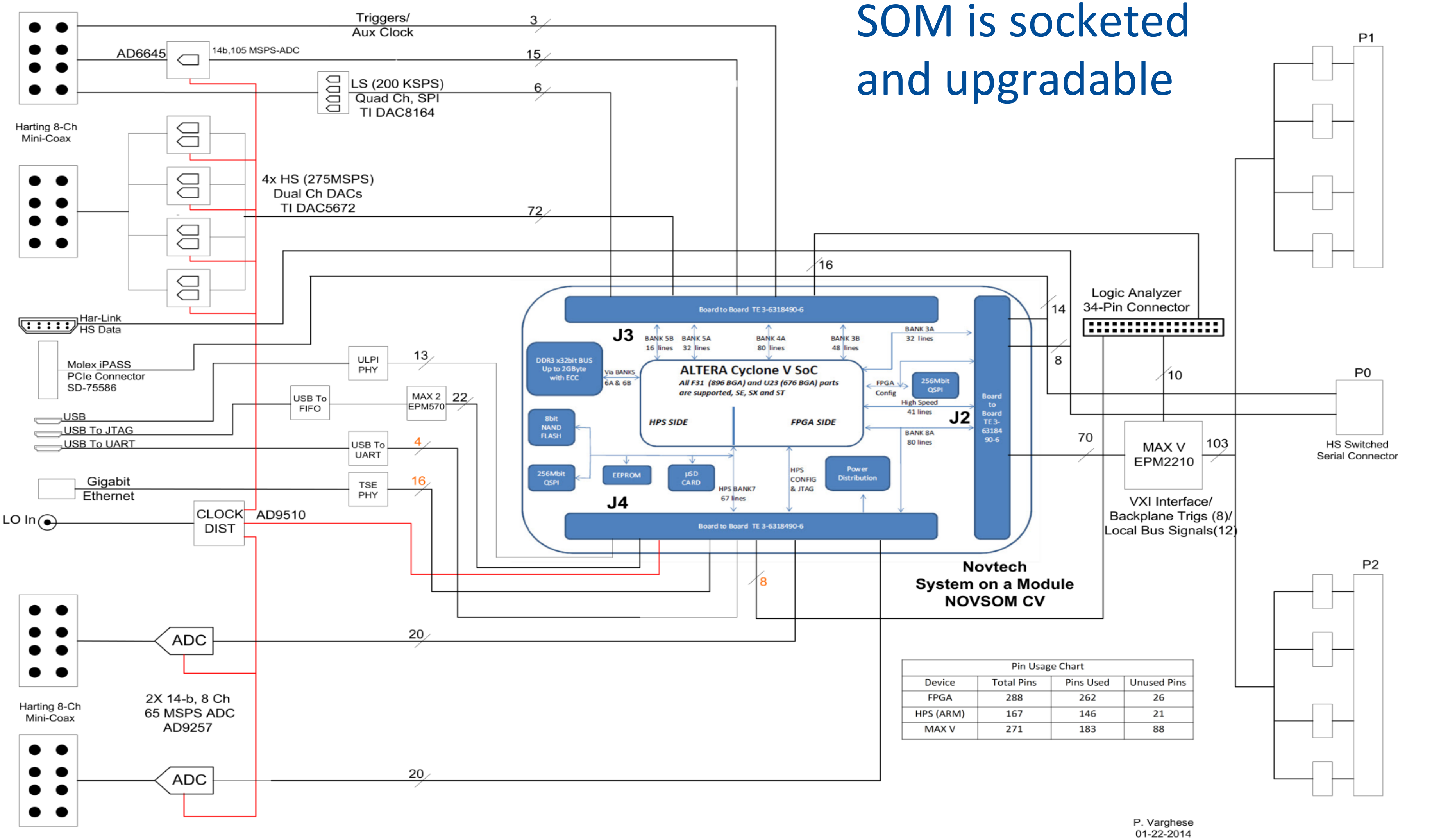
PIP-II LLRF 4 Cavity LLRF Rack Layout

Down converters for PXIE are done
Controller, PZT amp, stepper motor controller, Up converter in design stage



System on Module Multi-cavity Field Controller (SOM-MFC)

SOM is socketed and upgradable



Pin Usage Chart

Device	Total Pins	Pins Used	Unused Pins
FPGA	288	262	26
HPS (ARM)	167	146	21
MAX V	271	183	88

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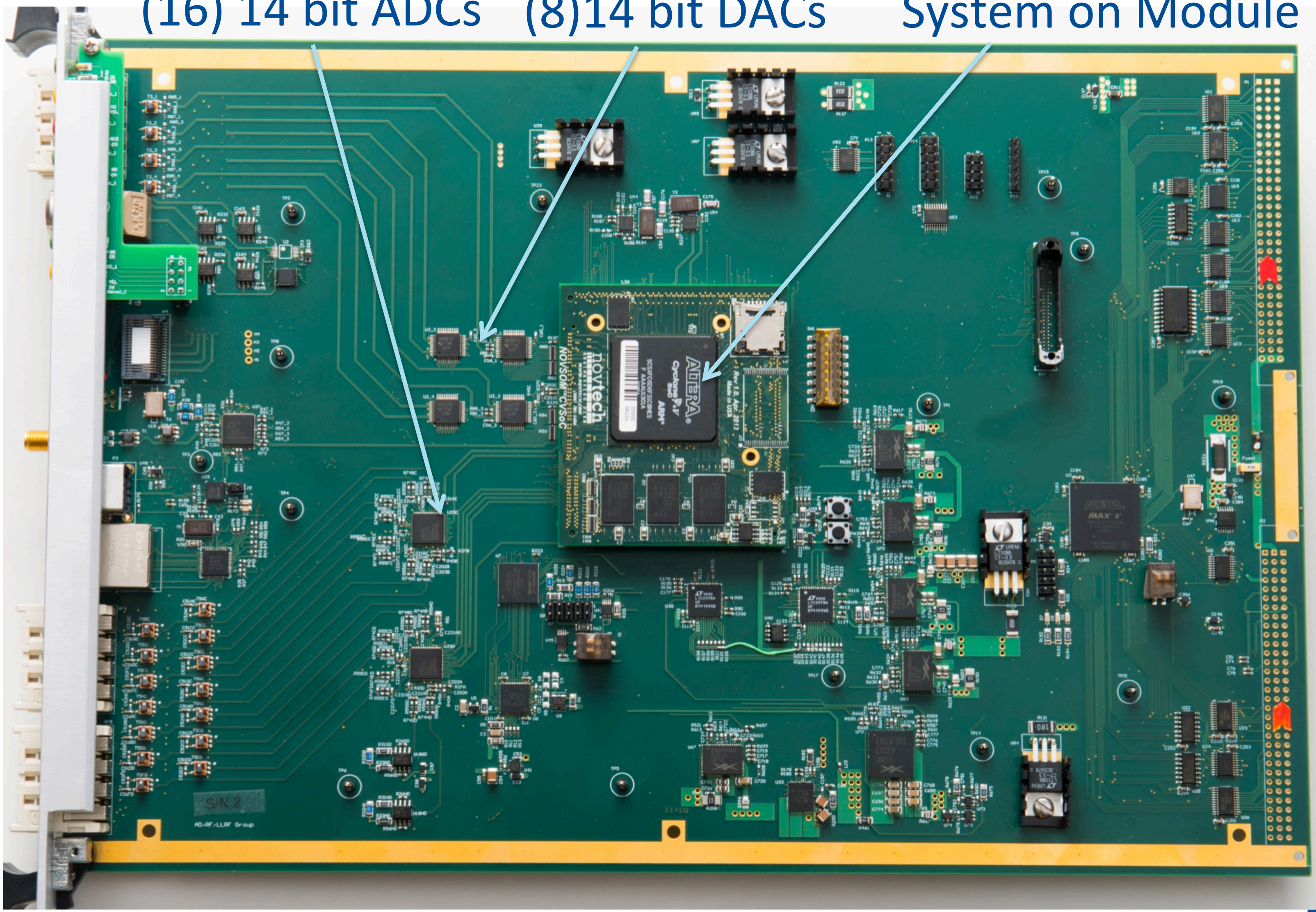
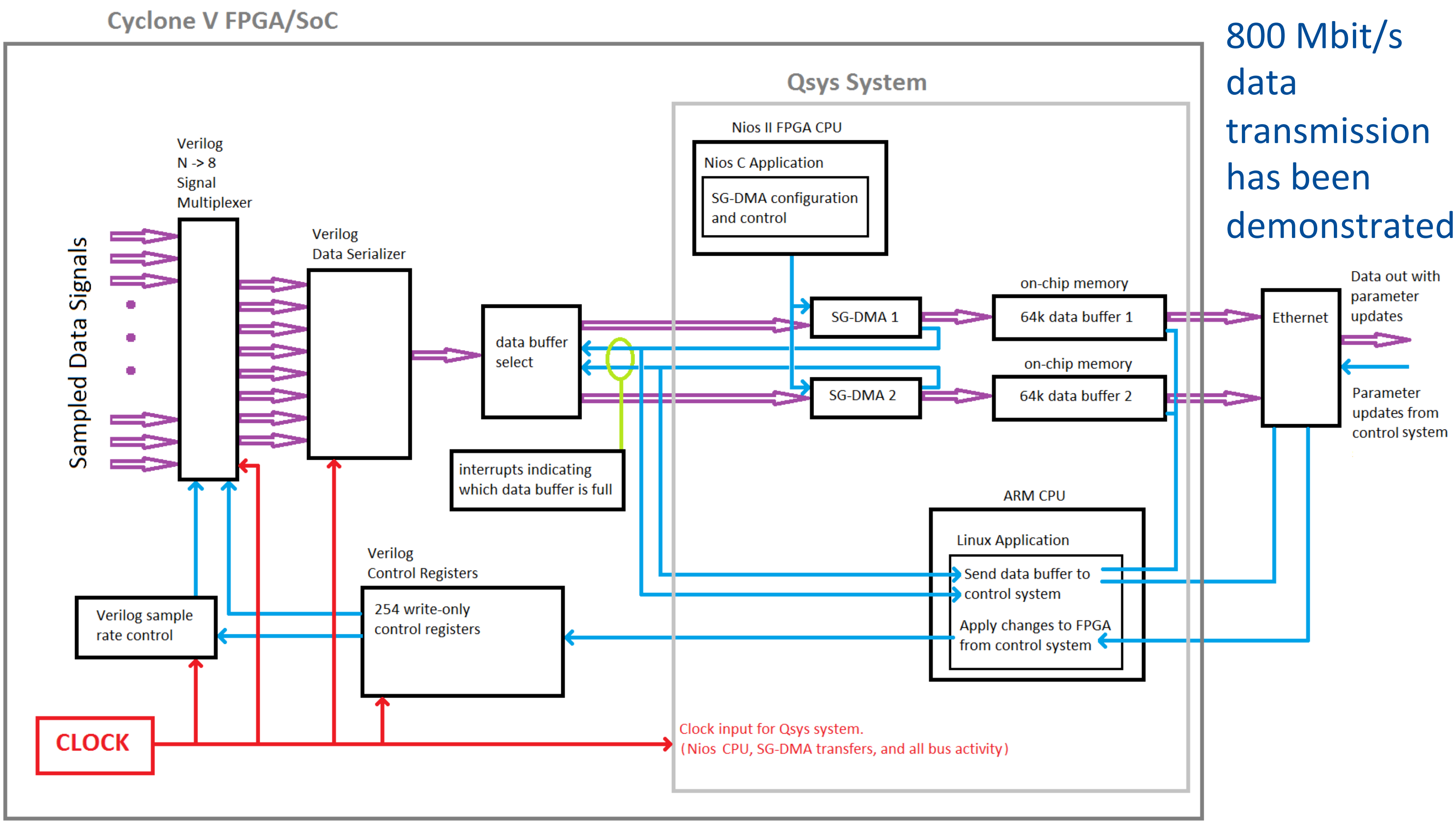
System on Chip Multi-channel Field Controller



Dual core Arm processor with FPGA may eliminate the need for a backplane and CPU card

SOC Data Acquisition Software / Firmware Model



800 Mbit/s data transmission has been demonstrated

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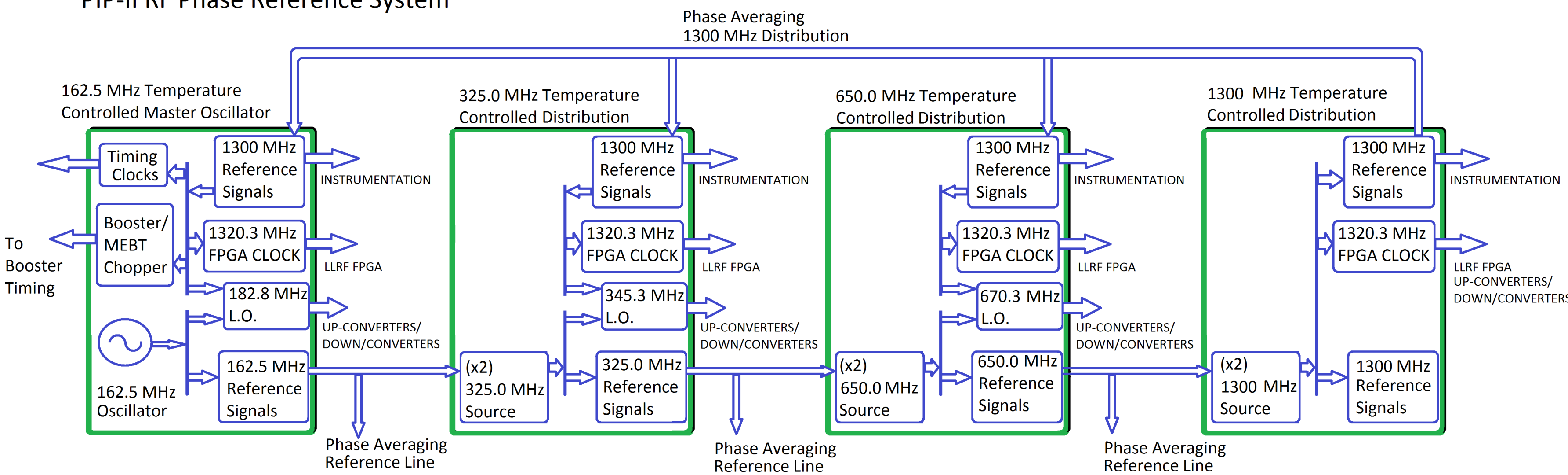
Phase Reference Lines (162.5, 325, 650 ,1300 MHz)

PIP-II RF Phase Reference System



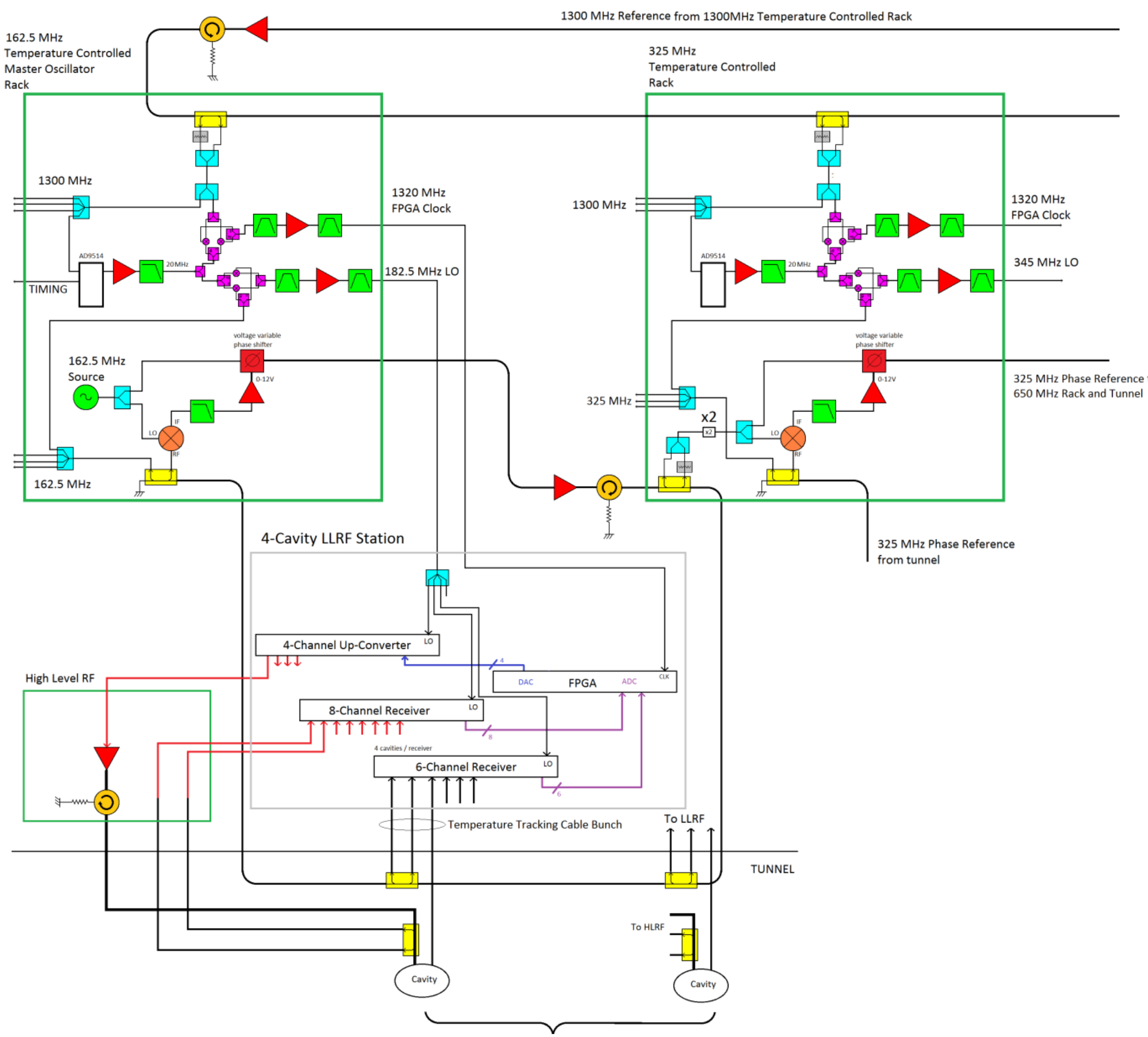
Multi-frequency Phase References and Local Oscillators
We are building up the first sections for PXIE

Details of First 162.5 MHz RF Section

Phase stability across harmonics (400 fs)

Temperature controlled racks and component plates

We have this experience and see a path forward



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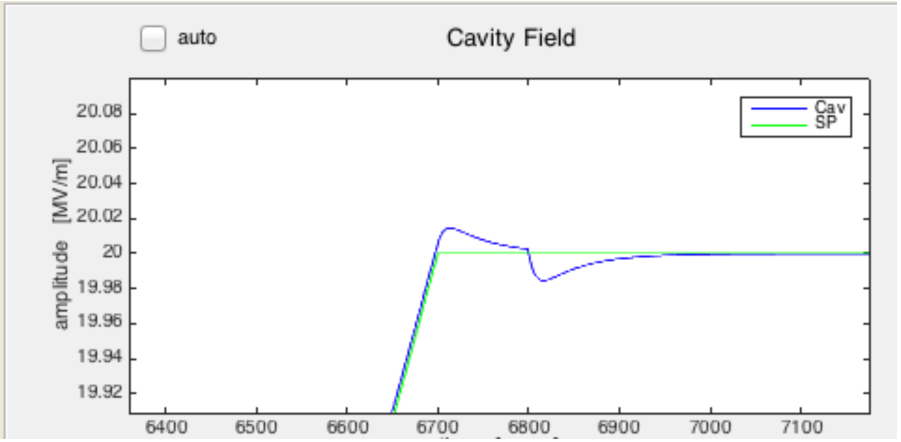
Primary Technical Risks

- Resonance Control for 5 new cavity designs
  - Lorentz Force Detuning compensation for narrow bandwidth cavities operated in pulsed mode
  - New cavity designs with new mechanical properties
  - ~20 Hz half BW with expected 420 Hz Lorentz Force Detuning in SSR1 (SSR1 is now pulsed)
- Development of the LEBT/MEBT Chopper Program Module
  - Wideband beam-based learning algorithm
- Regulation of amplitude and phase is 10^{-3} with 10^{-4} regulation during the pulse using beam based feedback

Regulation of beam energy to ~1e-4

- Strategy- regulate cavity fields to 0.1% and 0.1 deg.
- Measure beam energy in the bends with BPMs and time of flight
- Correct energy intra-pulse and learn pulse to pulse
- Question – can the feedback system servo loop control disturbances to the 1e-4 level?
  - Pgain = 500, Igain =9e6
  - feedforward turned off
  - beam loading starting at 6800us

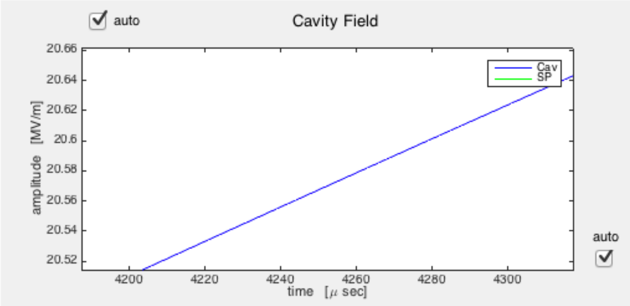
HB650 with 64 kW PA



- Answer – yes, short term
  - If detuning is not more than 1 half cavity BW
  - if beam based calibration can work at this level

Regulation of beam energy to ~1e-4

- Question – How fast can the RF respond to a gradient change request?
  - For the HB650 cavities driven at the full 60 kW with 20 Hz detuning and beam loading
    - a 0.1% takes about 20 microsecond
  - For the HB650 cavities driven at the full 60 kW with 20 Hz detuning and beam loading
    - a 0.1% takes about 4 microsecond



- Question – Do we have enough power overhead and have we optimized for cryo loading?
  - more power is a conservative option (I'm not opposed)
  - Optimizing for cryo, RF PA design choices, loaded Qs is something that will take time and may require more experience with the new cavities

Conclusions

- The LLRF Group is building and install for the R&D effort at PXIE to cover the RFQ and Buncher cavities
  - Development of a next generation system controller card
  - Development of the multi-frequency reference
  - RFQ resonance control
- SRF Resonance control collaboration is gearing up effort as cavities become available for test
  - Good early results to be transformed into a robust operational system
  - A good compromise point between pulsed and CW operation to be determined for RF power and loaded Qs for all cavity types
- Collaboration with India will get off the ground this year with an engineer appointed to LLRF for 2 years
- Real testing is just starting with SSR1 coupler / tuner / PA