Project X ICD-2
Low Level RF

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Project X Collaboration Meeting
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Project X

Outline

- Scope of Estimated Work
- Boundary Conditions /Assumptions
- Basis of Estimate
- Technical Risks/Associated Cost Exposure
- Potential Technical Revisions
- Role of Outside Collaborators
- Summary

Project X

Scope of Estimated Work

- The primary global function of the RF Control System is to regulate the RF fields in all accelerating cavities to maintain required beam energy and emittance
  - Global regulation requires information from beam based instrumentation and sector vector sums created from multiple stations
    - Exception handling for events such as a quenched cavity
  - Cavity field regulation is performed by the local LLRF system which controls a klystron and two cryomodules
  - Cavity phase regulation is in relation to a Master Oscillator signal via the phase Reference line
- A local LLRF system
  - Receives program requests from global control and localized real-time beam based feedback
  - Demodulates over 60 RF signals from the cryomodules, RF, and beam pickups
  - Provides Cavity Field regulation by control of the klystron drive and the Ferrite Vector Modulators the RF drive fast and slow cavity tuners
  - Provides Cavity Resonance control with motorized and piezo cavity tuners
  - Provides self calibration and diagnostics

Project X — Boundary Conditions & Assumptions

- LLRF interface to other systems
  - Control and Timing system
    - ➢ The primary Control System interface is via Ethernet connection to the crate level CPU. This connection scaler settings and reading, alarms and limits and waveform capture
    - ➢ LLRF provides synchronous reference clock signals to the Distributed Timing system and receives “LlrfStartTrigger” (active high LVDS)
  - HLRF and station interlocks
    - ➢ LLRF provides the drive signal to the klystron drive amplifier (10dBm FS)
    - ➢ LLRF receives coupled port forward and reflected power signals from Drive amplifier and several waveguide pickups. (10dBm FS @ receiver)
    - ➢ LLRF provides a “LlrfReady” signal (active high LVDS)
    - ➢ Receives an “RfInhibit_n” (active low 50 Ohm)
  - Machine Protection system
    - ➢ LLRF provides a “GradientRegulated” signal (undefined interface)
    - ➢ LLRF provides a “RfTrip” signal (undefined interface)

Boundary Conditions & Assumptions

- LLRF interface to other systems
  - Cryomodule
    - LLRF receives forward, reflected, and cavity transmitted RF signals for each cavity
    - LLRF drives stepping motors and piezo actuators
  - RF protection system
    - LLRF provides cavity RF signals
  - Instrumentation and Diagnostic
    - LLRF provides RF Phase Reference signals to diagnostic systems
    - LLRF receives beam phase signals from beam detectors

LLRF: assumptions

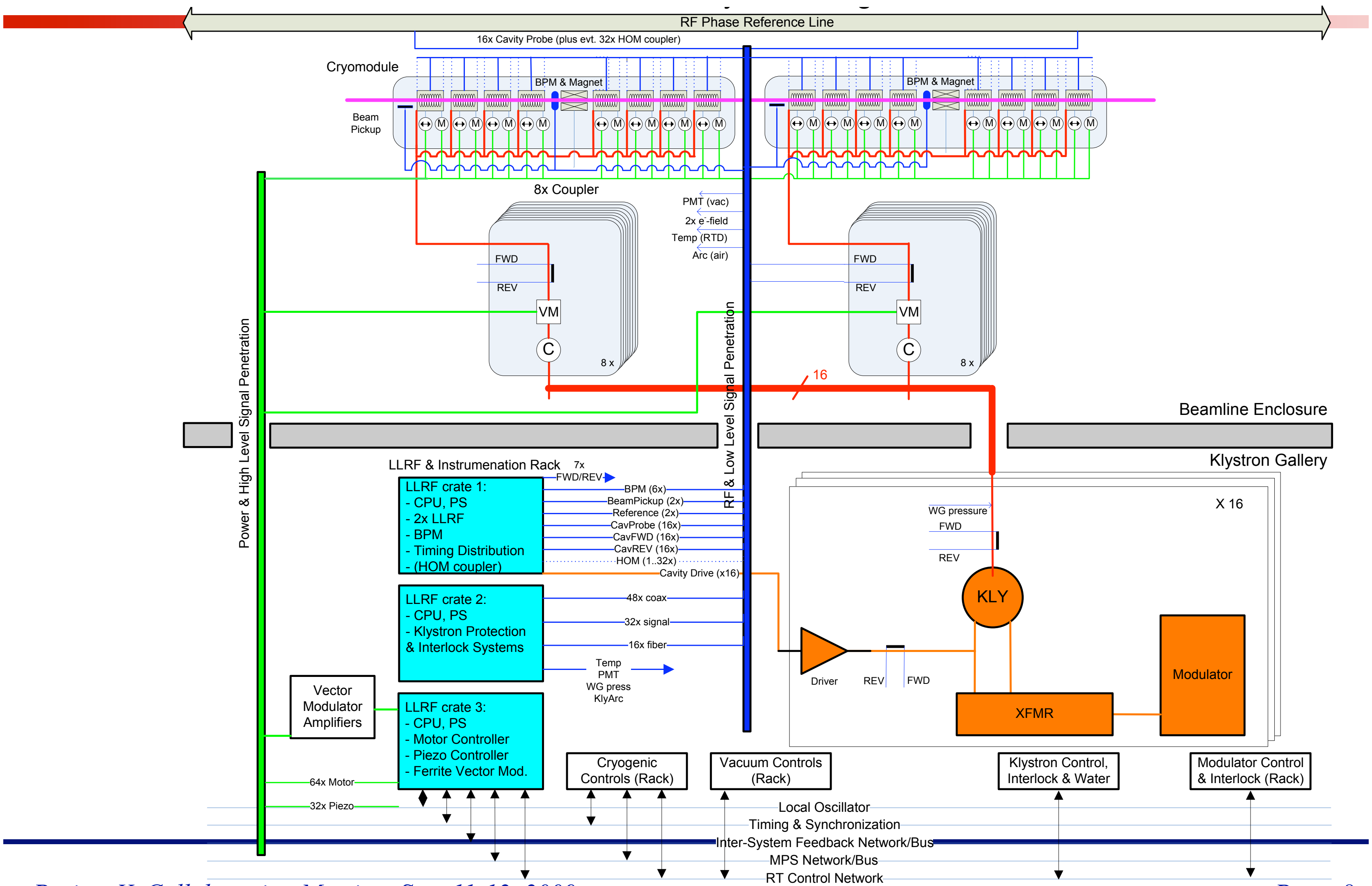
- Main Linac: LLRF equipment will reside in the Klystron Gallery
- Tight regulation of cavity parameters
  - R/Q of cavities - needed for beam based calibration
  - Frequency of passband modes
- Negligible ground motion over the length of the linac
- Internal hardware and software design with outsourced manufacturing
- There will be sufficient RF power headroom for regulation
- LLRF will not be a part of the personnel protection systems
- LLRF will be a secondary system in the machine protection systems
- The ILC construction LLRF Group will have control over most decisions that affect system costs

Project X ICD1-ICD2 Requirements

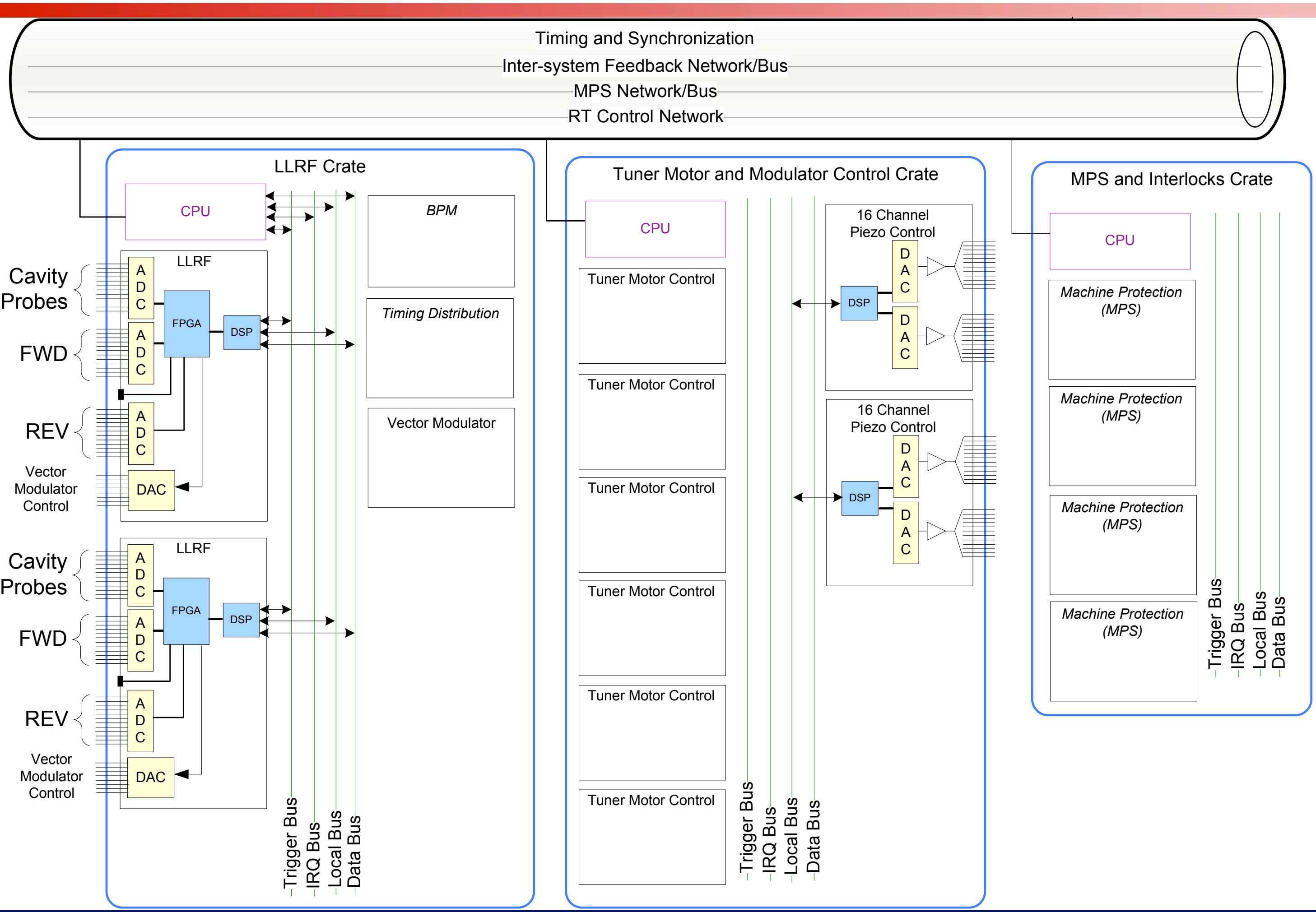
- Many of the RF control requirements are the same for ICD1 and 2
- Microphonics have been studied and require about 20% power overhead with the 1ma beam current

	ICD-1	ICD-2
Duty Factor	pulsed 10 Hz, 2ms	CW operation
Beam Current	25mA	1mA
Cavity/PA Ratio	16:1	1:1
Regulation	1 Deg., 1%	1 Deg., 1%
Control loops	GDR	GDR, SEL

Project X LLRF for Two Cryomodules

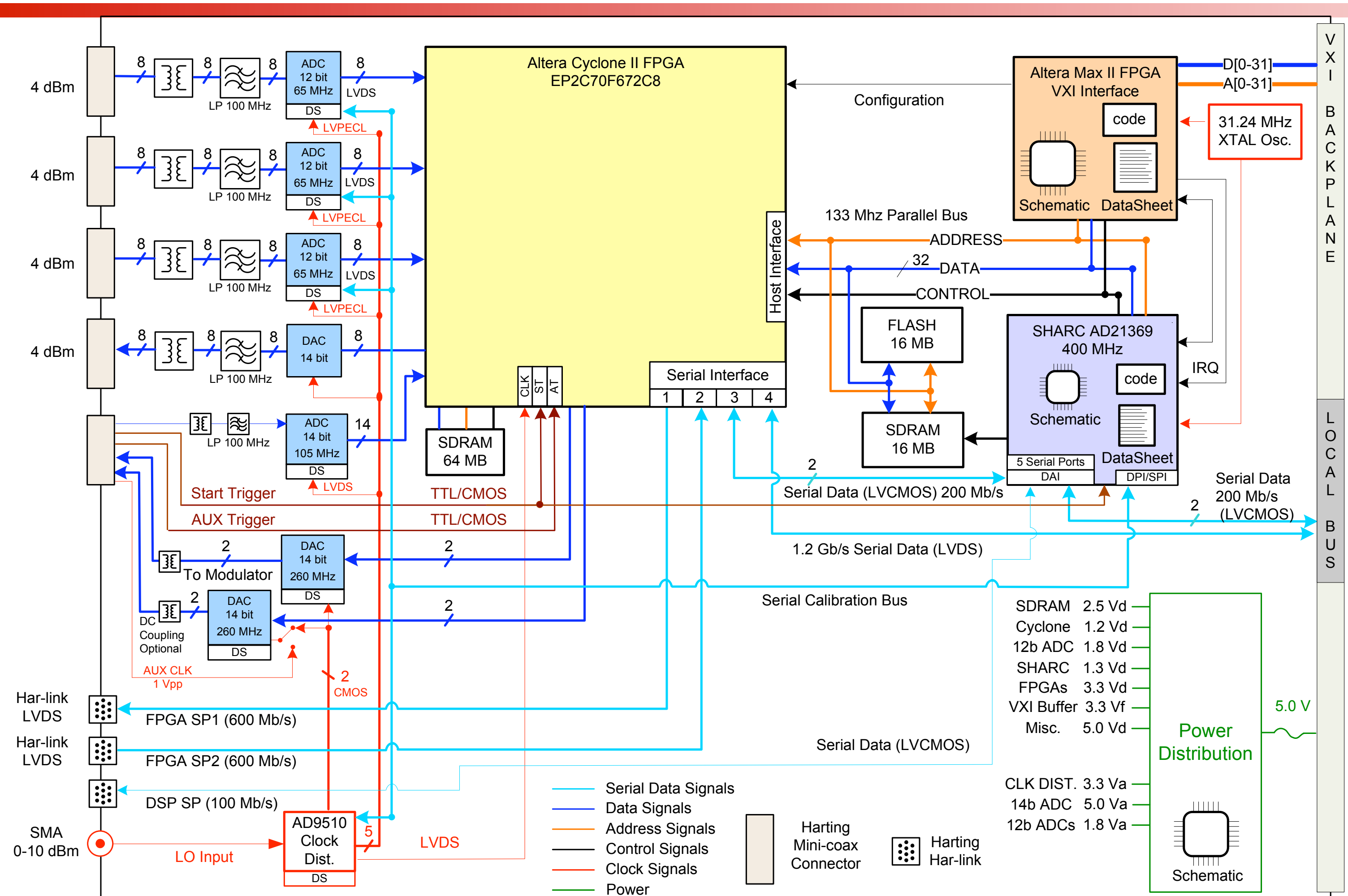


Project X Crate Level Diagram



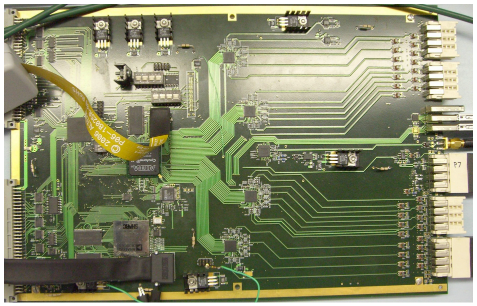
24 Channel Receiver
8 Channel Controller and Transmitter

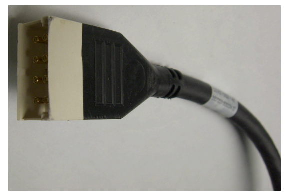
Project X



8 Ch Receiver and MFC

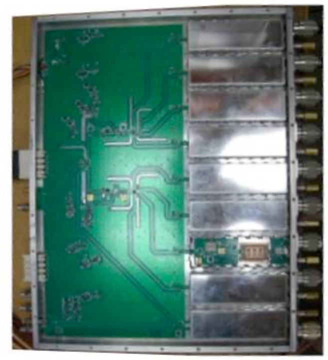
Multi-Channel Field Control Module

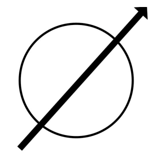




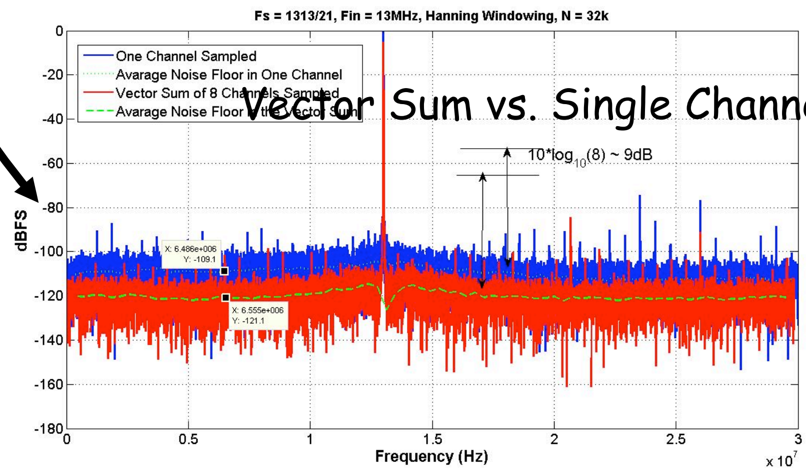
Harting IF Mini-coax Connector

8 Channel Rc





Phase Adjustment



Vector Sum vs. Single Channel

<u>Measured SNR for one channel (12bit ADC):</u>

SNR@fs/2 = 112dB - 10log10(32k/2) = 70dB

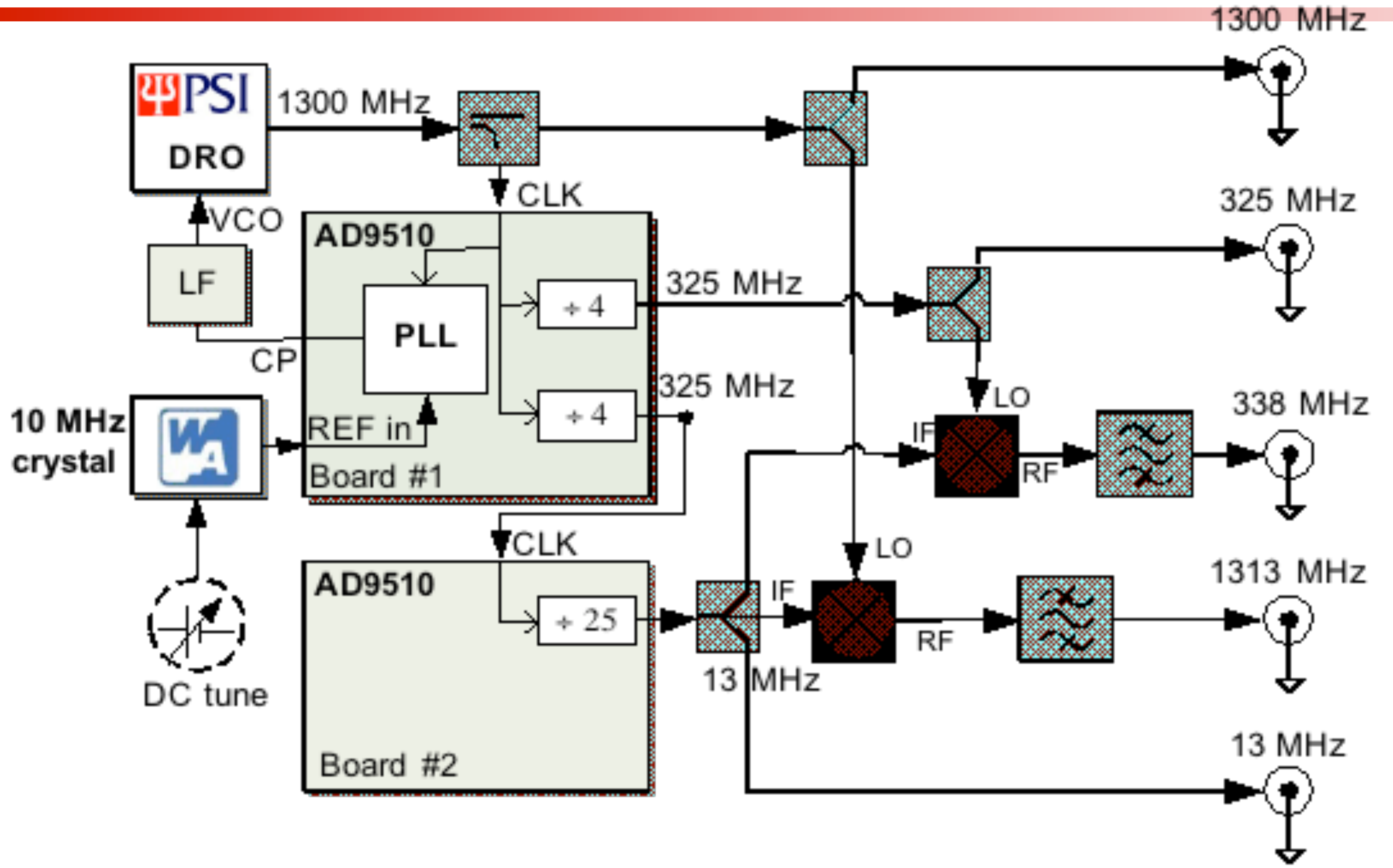
<u>Measured SNR for vector sum (8x12bit ADC):</u>

SNR@fs/2 + 10log10(8) = 79dB

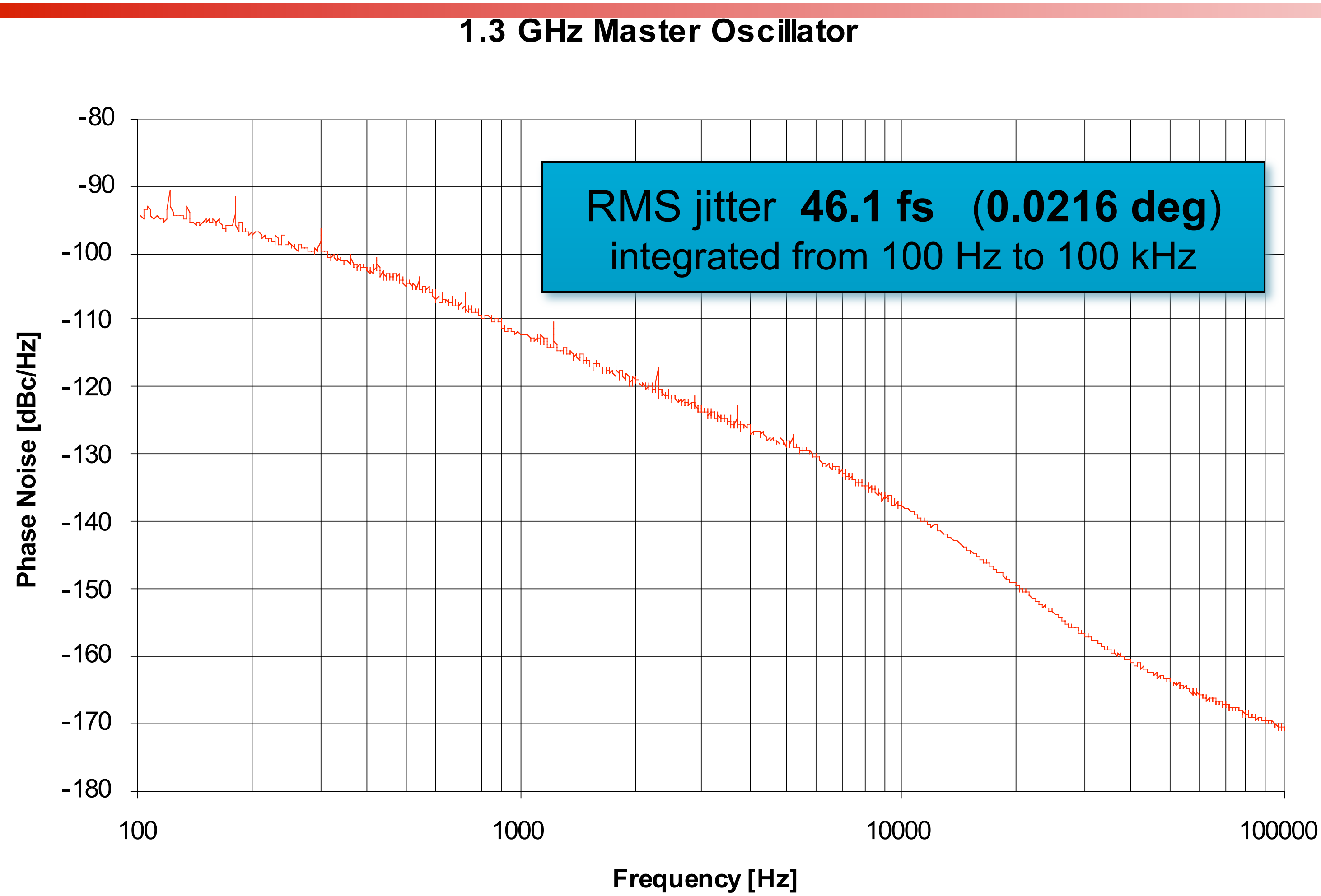
The SNR -156dBc/Hz (0.0016% BW:1MHz) is expected.

Project X

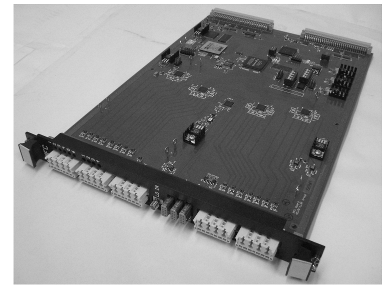
Low Noise Master Oscillator

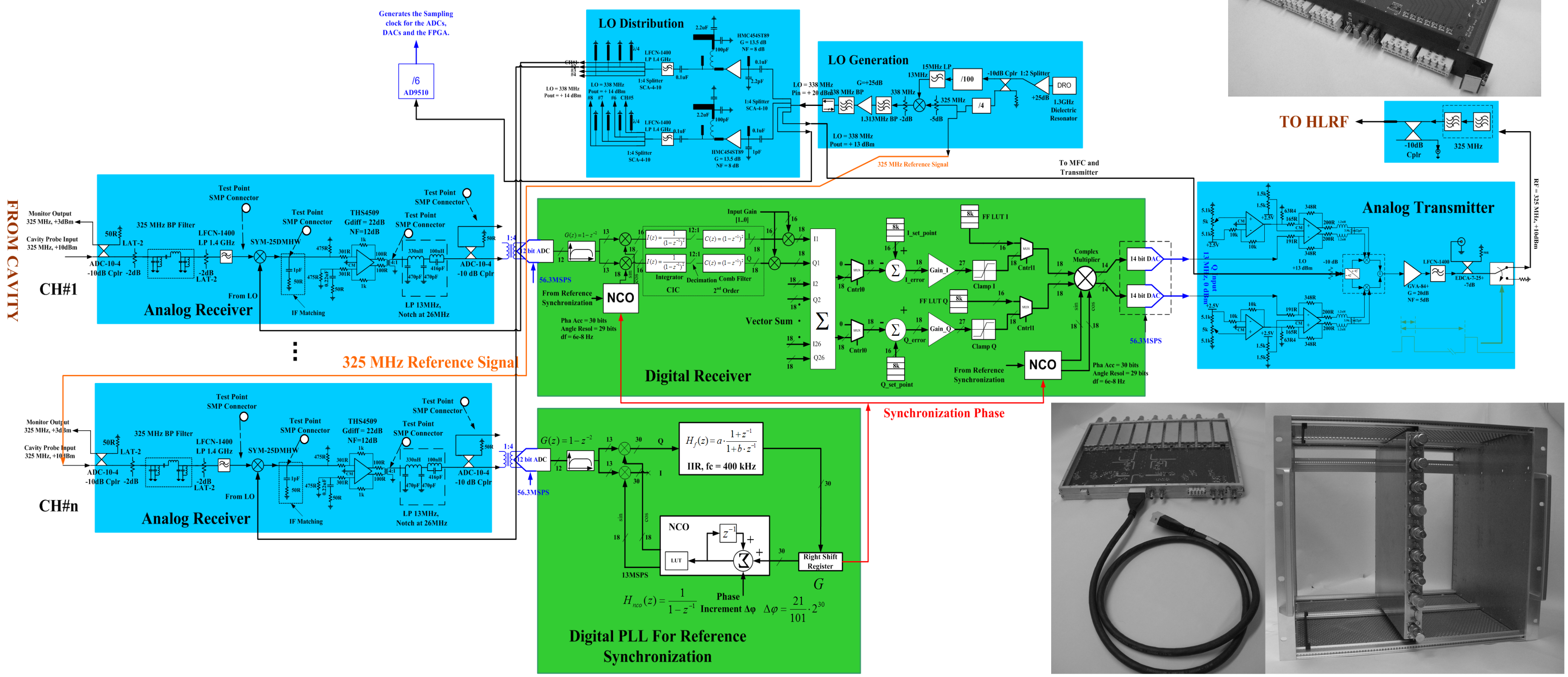


Phase Noise of 1300 MHz Master Oscillator



325 MHz LLRF System
With MO and LO Generation





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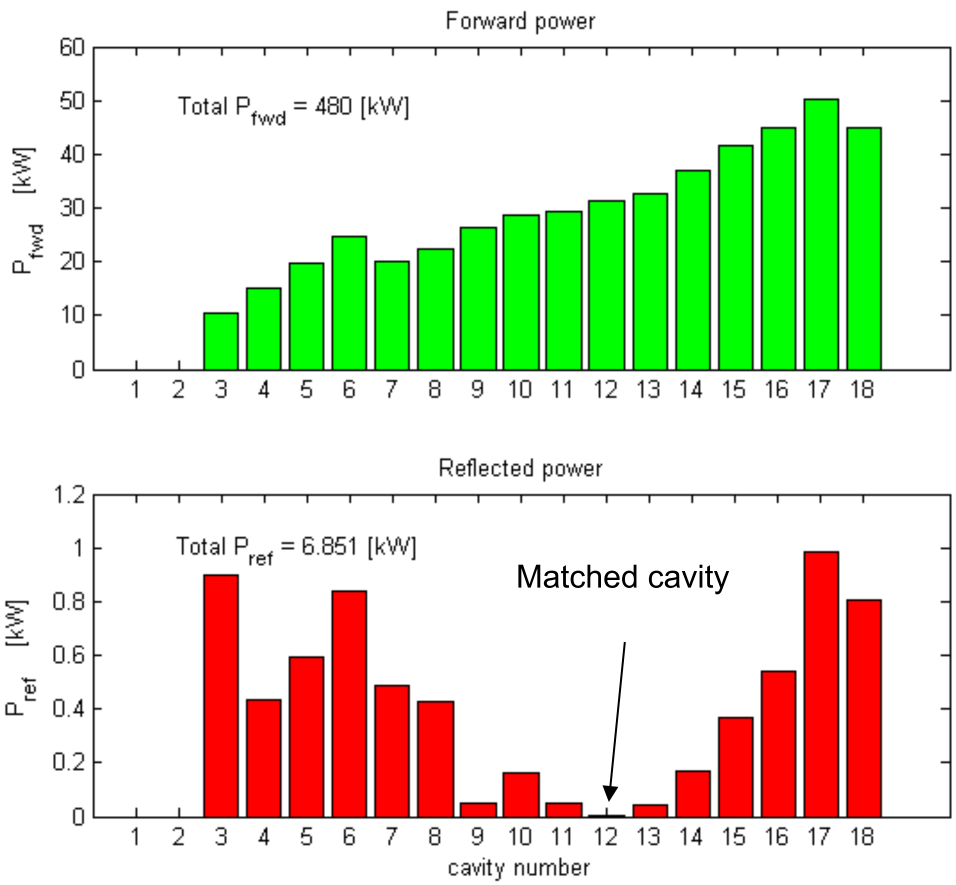
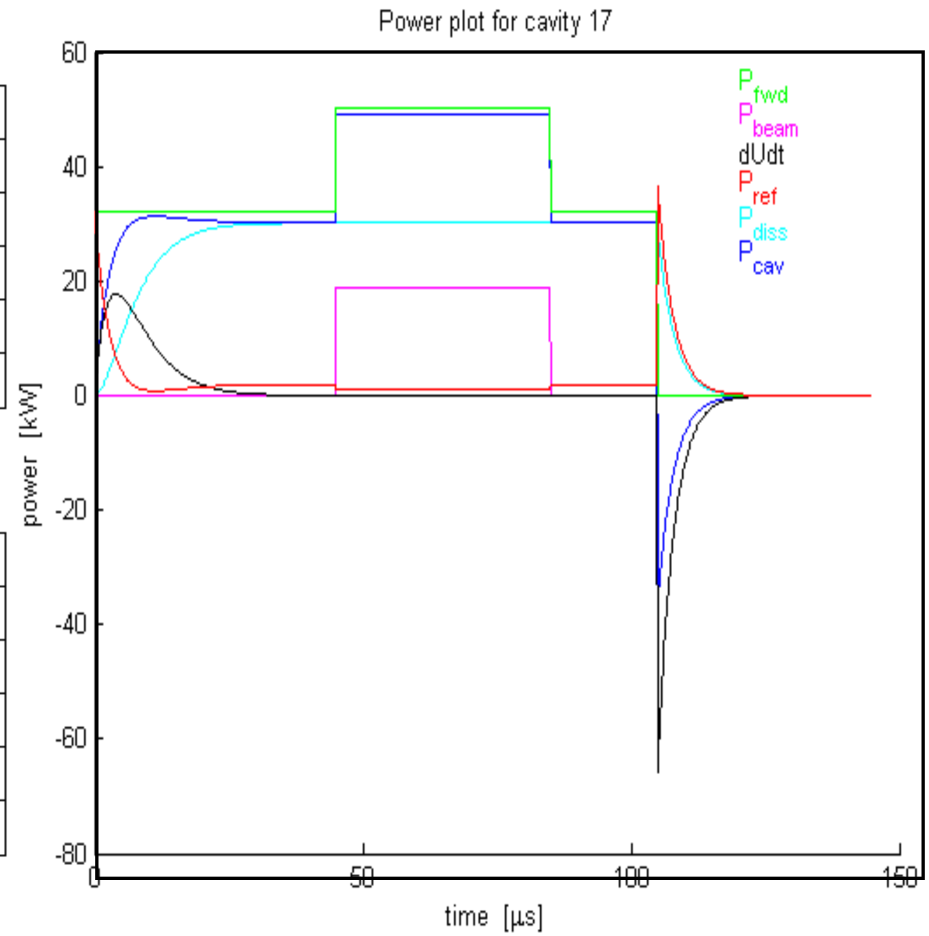
Beam loading compensation

FF klystron amplitude and phase modulation



Steady state power during beam loading



Power variations during a pulse

Project X

RCS Parameters

Table III-8: Main Parameters of RCS

Energy, min/max, GeV	2/8
Repetition rate, Hz	10
Circumference, m (MI/6)	553.2
Tunes, ν_x/ν_y	18.42 / 18.44
Transition energy, GeV	13.36
Number of particles	2.6×10^{13}
Beam current at injection, A	2.2
Transverse 95% normalized emittance, mm mrad	25
Space charge tune shift, inj.	0.06 [1]
Norm. acceptance at injection, mm mrad	40
Harmonic number for main RF system, *h*	98
Harmonic number for 2-nd harmonic RF system,	196
RF bucket size at injection, eV s	0.38
Injection time for 1 mA linac current, ms	4.3
Required correction of linac energy (kinetic) during injection	1.2%
Total beam power required from linac, kW	90[2]
Total beam power delivered by RCS, kW	340

Project X

RCS LLRF

- Global Radial Position and beam PLL control loops
  - Frequency and acceleration phase angle
    - 50.33-52.81 MHz sweep
- RF station slave controllers for first and second harmonic stations
  - 16 first, 10 second harmonic cavities
  - Beam generated voltage is 150 times V_{cav} at extraction requires very high RF suppression of fundamental and revolution harmonics
  - Local direct RF feedback, beam based feedforward and comb filters
- Controllers and comb filters use the same FPGA based hardware as the Linac
- Simulation work is needed

Collaborators

- We are currently working with Alessandro Ratti and Larry Doolittle from LBNL. This will develop with a completed MOU
- Ongoing collaboration with ILC groups from KEK and DESY
- Ongoing collaboration with Argonne
- Close ties with JLAB
- Internal collaboration at Fermilab from AD, CD, and TD

Development Plans for 2010…

- Anticipated inputs from other efforts
  - Much development work will be done within the current HINS and NML projects. Current activities include A0, HTS, CC2, HINS, NML, ILC
  - FNAL and LBNLwill collaborate on
    - Resonance control algorithm development
    - Calibration of the receiver chain
    - Error handling
    - Prepare design for CD-1 review
- Booster Ring LLRF will extrapolate off of MI Comb filter project and off of Linac controllers
- Presently not expecting major changes to the Main Injector LLRF system
- Modeling and simulation efforts
- Other collaboration efforts?

Open Questions

- What will be the “best” electronics packaging in 2015?
- Are there new technologies emerging that we should be exploring?
- Build or buy LLRF hardware and software?
- Single or multiple cavity per power amplifier?
- Ferrite Vector Modulators cost reduction?
- RCS beam loading issues
- Spoke resonators or DTLs?

Basis of Estimates

- Review of existing systems SNS, Jlab, DESY, KEK, FNAL
- Vender quotes on BOMs with production quantities
  - Receiver - FNAL prototype BOM
  - Controller - FNAL prototype BOM
  - Cable - quote from vendor
  - Piezo controller, vector modulator controller, drive amplifier, phase reference - best estimate
  - Final costs may be lower with a true bidding process
  - See paper documents for details
- Prototypes of major components
- Estimate of uncertainty ~ 30%
  - Copper, steel, management structure and requirements, high reliability requirements, present design level

2 GeV Linac Cost

Cost Summary for Project X - LLRF

	# Cavities	#Cryomodules	# LLRF Stations	Cost / Station (k $)	Total Cost (k $)
325 MHz RFQ & 2 Bunchers	3		0.5	$ 79.99	$ 40
325 MHz SSR0 (beta=0.117)	16	3	1.5	$ 89.32	$ 134
325 MHz SSR1 (beta=0.22)	18	2	1	$ 90.02	$ 90
325 MHz SSR2 (beta=0.4)	33	3	1.5	$ 90.02	$ 135
325 MHz TSR (beta=0.6)	42	7	3.5	$ 90.02	$ 315
1300 MHz SILC (beta=0.81)	72	12	6	$ 90.02	$ 540
1300 MHz ILC (beta=1)	68	9	5	$ 90.02	$ 450
LLRF Total Station Cost	252		19		$ 1,704
Cable plant					$ 187.25
Master Oscillator					$ 75.00
Local Oscillator&Dist.					$ 63.20
Synchonizaton to ring					$ 80.00
Phase Reference Line					$ 215.08
Global Energy Controller					$ 50.00
Machine protection					$ 95.00
Test Stand 325MHz					$ 89.32
Test Stand 1300MHz					$ 90.02
Spares					
Test Equipment					
			Total LLRF System Cost ($k)		**$ 2,375**

Potential Technical Revisions

- State of the art RF electronics changes rapidly and will affect circuit and possibly system topology. A ten years extrapolation into the future is a stretch but the sign of most cost change is generally in our favor
    - ➢ Crate standards including possibly no crate
    - ➢ Direct sampling of RF signals
    - ➢ Radiation hardness of components – sample at the cryomodule
    - ➢ Technology for fiber and copper reference distribution
    - ➢ Next generation FPGAs and ADCs
    - ➢ New technologies
  - – No big cost drivers
- LLRF role in MPS is presently largely undefined
  - – Design decisions could add complexity and expense

LLRF activities for Project X at CD

- Real Time Simulator (RTS)
  - The RTS currently supports 4 cavities.
  - The current simulator models include superconducting and normal conducting cavities, individual cavity synchronous phases and beam loading conditions.
  - Future work:
    - Expand the RTS to simulate a full Project X RF unit and Project X front end LINAC.
    - Improve the user interface.

- Off line simulations
  - CD will complement AD effort in off line simulations for Project X.
  - CD will team up together with AD/LLRF to develop common models for the existing Matlab off line LLRF simulator.

LLRF activities for Project X at CD

- LLRF models
  - Complement AD/LLRF effort in modeling the LLRF problem for Project X.
  - Develop a machine parameter configuration to optimize RF fields in the cavities.
  - Calibration procedures.
  - Analyze and incorporate RF disturbances into the models.
  - Collaborate with TD in their Lorentz force detuning modeling.
- LLRF Control
  - Advance in the development of control algorithms.
  - Incorporate new control algorithms in the off line and real time simulations.
  - Implement the algorithms in firmware and measure results on field.
- Support Project X management
  - Support costing and documentation for reviews.
  - Participate of meetings and workshops.
  - Publish results.

LLRF activities for Project X at CD

- ESECON controller
  - Hardware
    - We have 10 working boards.
      - 3 at A0 photoinjector
      - 1 for HTS at Meson lab.
      - 1 for CCII at NML.
  - Firmware
    - All basic modules are working.
    - The firmware work will continue adding new blocks such as klystron linearization, beam loading compensation, a more sophisticated control, automation and calibration, etc
  - Software
    - We will support DOOCS operation and some level of development. It would be nice to migrate ESECON to the main Controls software for Project X.
  - Commissioning, operations and studies
    - Will be supported.