Director's Review of the Project X Cost Range Estimate: Low Level RF

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Project X Director's Review
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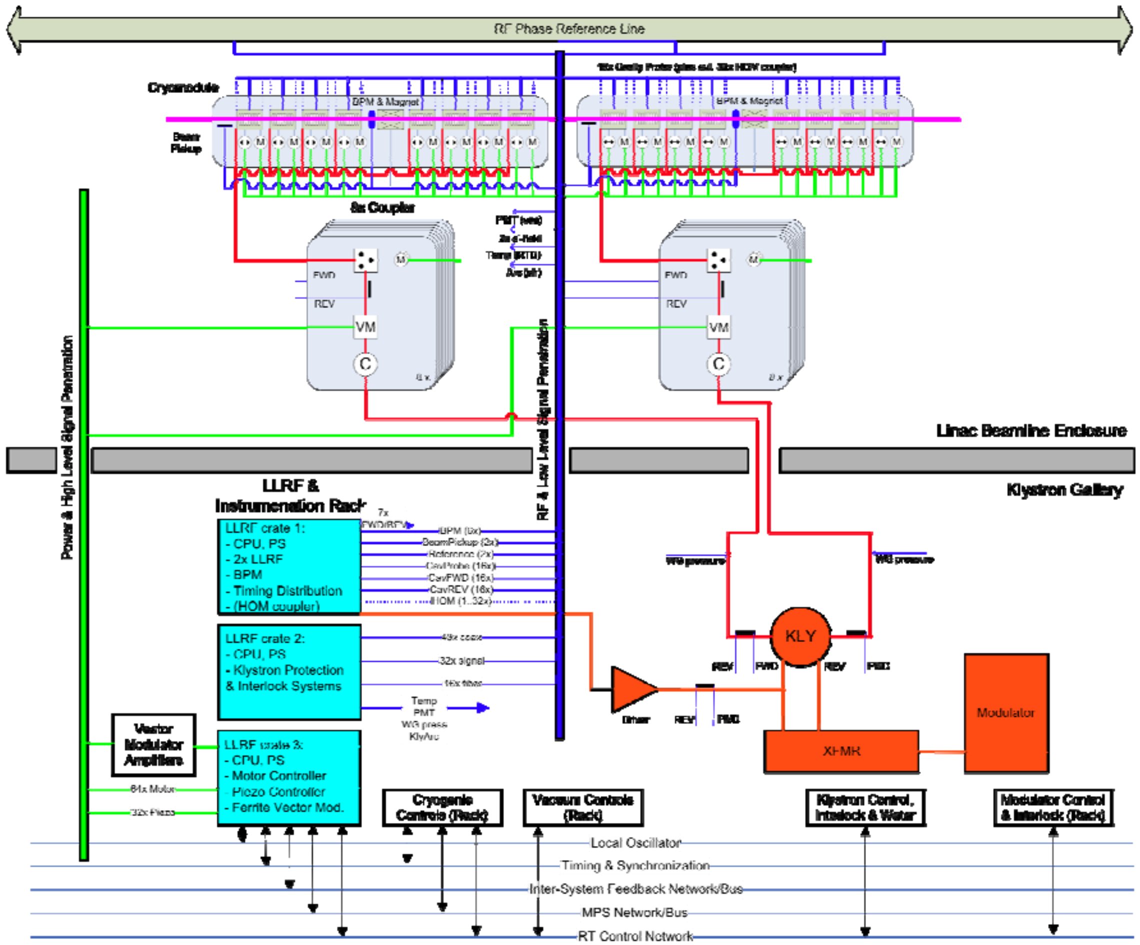
Outline

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

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 RF Station with 2 Cryo-modules



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

Boundary Conditions & Assumptions

- 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
  - We expect to gain from the experience of our collaborators
- Presently not expecting major changes to the Main Injector LLRF system
- Electrician and other trade work is not included
- Drive amplifiers for 325 MHz are in the LLRF budget, not in 1300 MHz

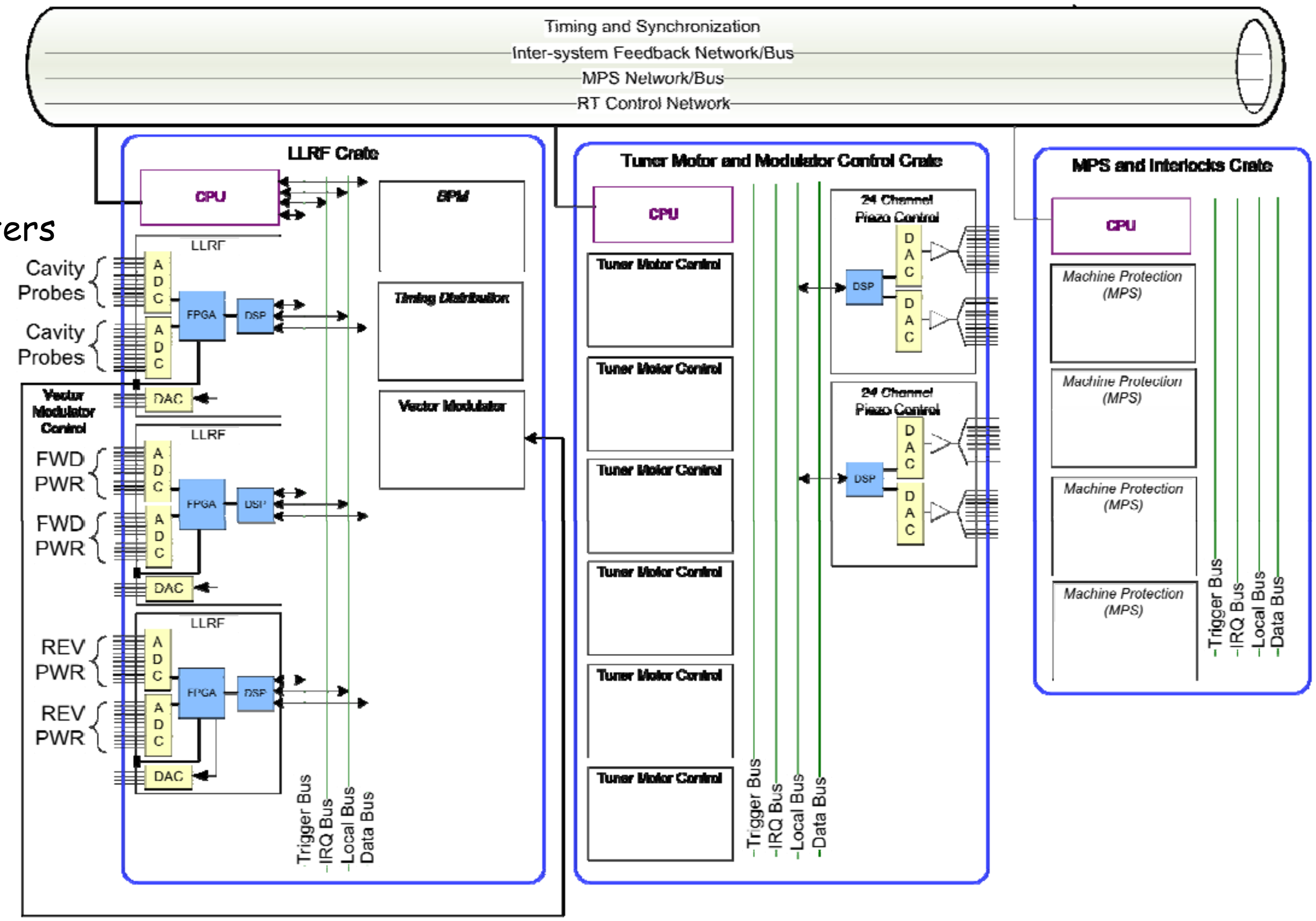
LLRF: assumptions

- 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

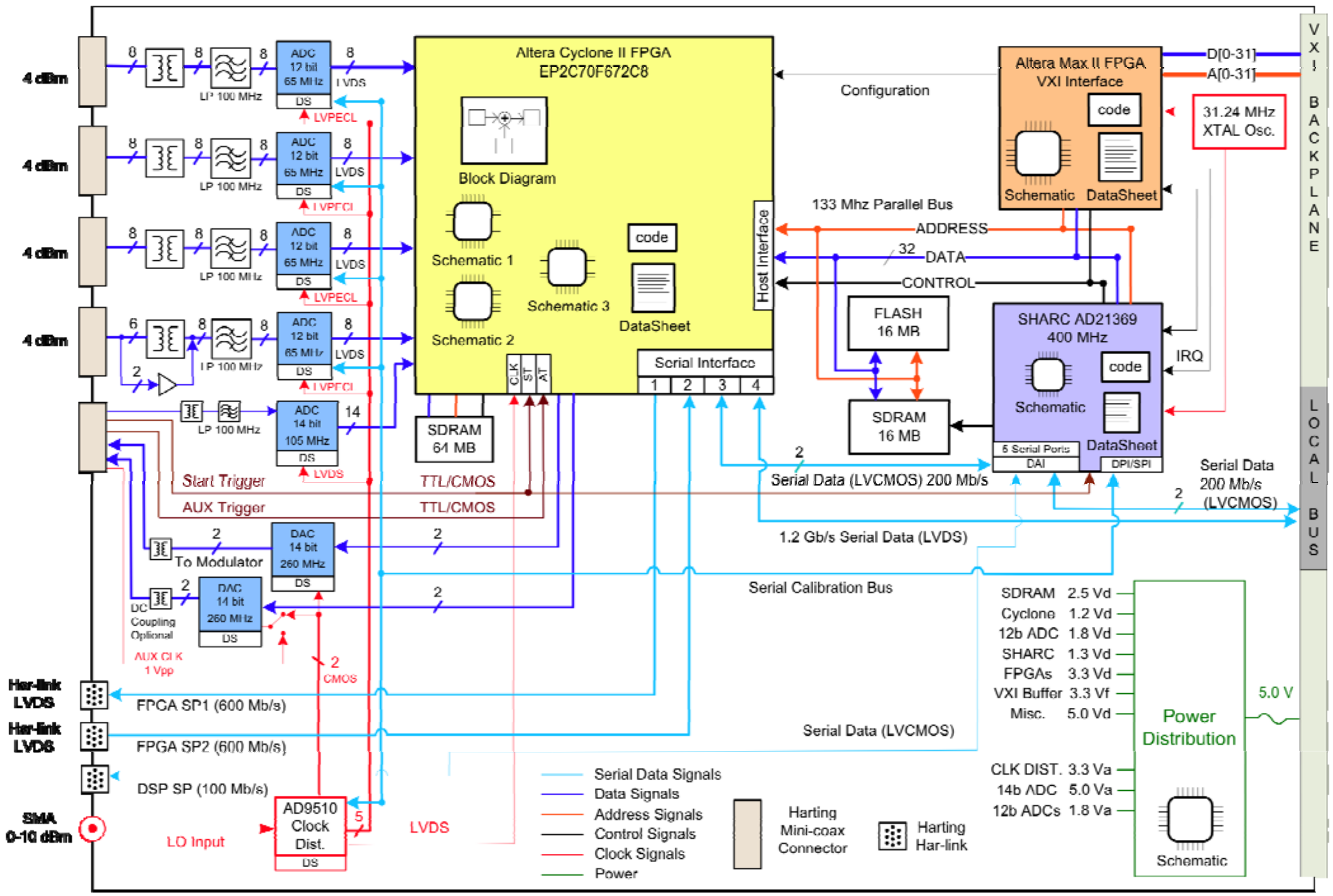
![Project X logo]

LLRF Rack Detail

Down-converters not shown



MFR Block Diagram



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

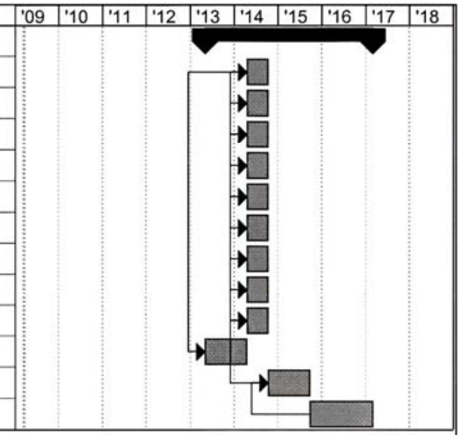
Project X

Basis of Estimate

Cost Summary for Project X - LLRF			
	# RF Stations	Cost / Station (k $)	Total Cost (k $)
325 MHz Warm Cavities	1	$ 116.69	$ 117
325 MHz Cold Cavities	7	$ 126.02	$ 882
1300 MHz Beta=0.81	4	$ 90.02	$ 360
1300 MHz Beta=1	19	$ 90.02	$ 1,710
LLRF Total Station Cost	31		$ 3,069
Cable plant			$ 305.51
Master Oscillator			$ 75.00
Local Oscillator&Dist.			$ 63.20
Synchonizaton to MI			$ 80.00
Phase Reference Line			$ 215.08
Global Energy Controller			$ 50.00
Machine protection			$ 155.00
	Total LLRF System Cost ($k)		**$ 3,858**

LLRF Gantt Chart

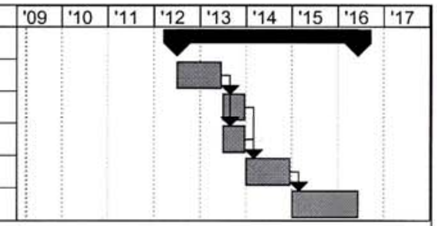
ID	WBS	Task Name	Duration	Start	Finish	Cost
1	**1.3.5**	**1.3GHz LLRF and Global LLRF Systems**	**1000 days**	**Mon 5/6/13**	**Fri 3/3/17**	**$3,013,790.00**
2	1.3.5.1	Beta = 0.81 LLRF Stations	125 days	Mon 4/21/14	Fri 10/10/14	$360,000.00
3	1.3.5.2	Beta = 1 LLRF Stations	125 days	Mon 4/21/14	Fri 10/10/14	$1,710,000.00
4	1.3.5.3	Cable Plant	125 days	Mon 4/21/14	Fri 10/10/14	$305,510.00
5	1.3.5.4	Master Oscillator	125 days	Mon 4/21/14	Fri 10/10/14	$75,000.00
6	1.3.5.5	Local Oscillator and Distribution	125 days	Mon 4/21/14	Fri 10/10/14	$63,200.00
7	1.3.5.6	Synchronization to MI	125 days	Mon 4/21/14	Fri 10/10/14	$80,000.00
8	1.3.5.7	Phase Reference Line	125 days	Mon 4/21/14	Fri 10/10/14	$215,080.00
9	1.3.5.8	Global Energy Controller	125 days	Mon 4/21/14	Fri 10/10/14	$50,000.00
10	1.3.5.9	Machine Protection	125 days	Mon 4/21/14	Fri 10/10/14	$155,000.00
11	1.3.5.10	1.3 GHz LLRF Final Design	250 days	Mon 5/6/13	Fri 4/18/14	$0.00
12	1.3.5.11	1.3 GHz LLRF Fab/Assy/Test	250 days	Mon 10/13/14	Fri 9/25/15	$0.00
13	1.3.5.12	1.3 GHz LLRF Installation & Checkout	375 days	Mon 9/28/15	Fri 3/3/17	$0.00



Project X

325MHz Gantt

ID	WBS	Task Name	Duration	Start	Finish	Cost
1	**1.2.9**	**325MHz LLRF**	**1028 days**	**Tue 7/3/12**	**Thu 6/9/16**	**$999,000.00**
2	1.2.9.1	325 MHz LLRF Final Design	250 days	Tue 7/3/12	Mon 6/17/13	$0.00
3	1.2.9.2	325 MHz Warm Cavities	125 days	Tue 7/2/13	Mon 12/23/13	$117,000.00
4	1.2.9.3	325 MHz Cold Cavities	125 days	Tue 7/2/13	Mon 12/23/13	$882,000.00
5	1.2.9.4	325 MHz LLRF Fab/Assy/Test	250 days	Fri 1/3/14	Thu 12/18/14	$0.00
6	1.2.9.5	325 MHz LLRF Installation & Checkout	375 days	Fri 1/2/15	Thu 6/9/16	$0.00



Technical Risks

- Field regulation of multiple cavities from a single RF power amplifier using Ferrite Vector Modulators
  - Requires precise field control of each cavity's amplitude and phase
    - ➢ 325 MHz coaxial modulators & 1300 MHz waveguide modulators
      - Power handling
      - Control Bandwidth
- Resonance control of spoke resonator cavities
- Regulation with low Klystron power overhead
  - Nonlinear klystron behavior including AM to PM coupling
- Viability of low cost phase reference line and long run fiber
- The RD&D plan addresses all of these risks
    - ➢ For LLRF concerns, only FVMs are a large cost risk to the project
      - Simulations look promising

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

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

Summary

- The basic generation of LLRF hardware and software is becoming well understood. We can build it and make it work
- LLRF is a low cost and fairly low risk system on its own
  - It can be made into an effective controller
- Project X has several innovative technologies that may challenge regulation
  - Driving many cavities from one klystron by using Ferrite Vector Modulators
  - SRF Spoke Resonators in pulsed RF configuration
- RD&D at HINS and NML are critical to Project X LLRF development

- Thank You!

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.

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.

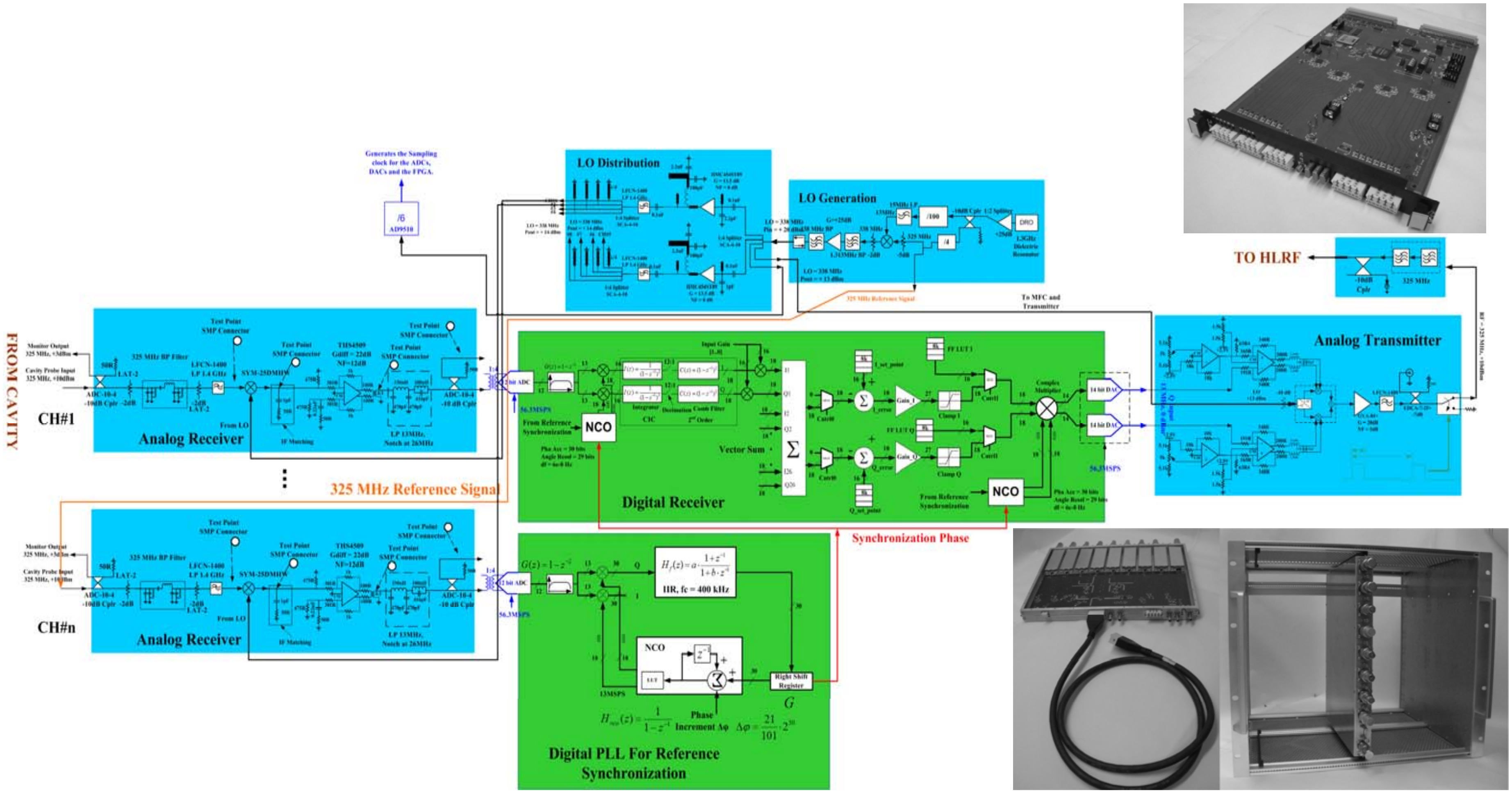
LLRF activities for Project X at CD

- 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.

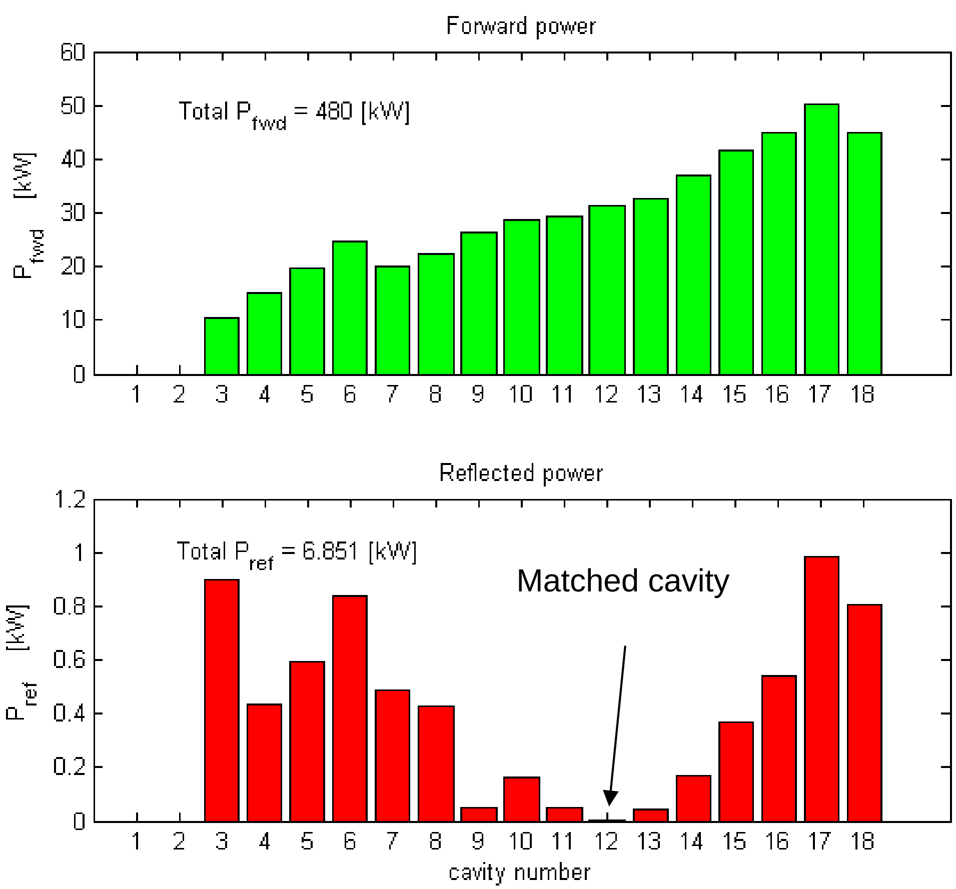
325 MHz LLRF System
With MO and LO Generation



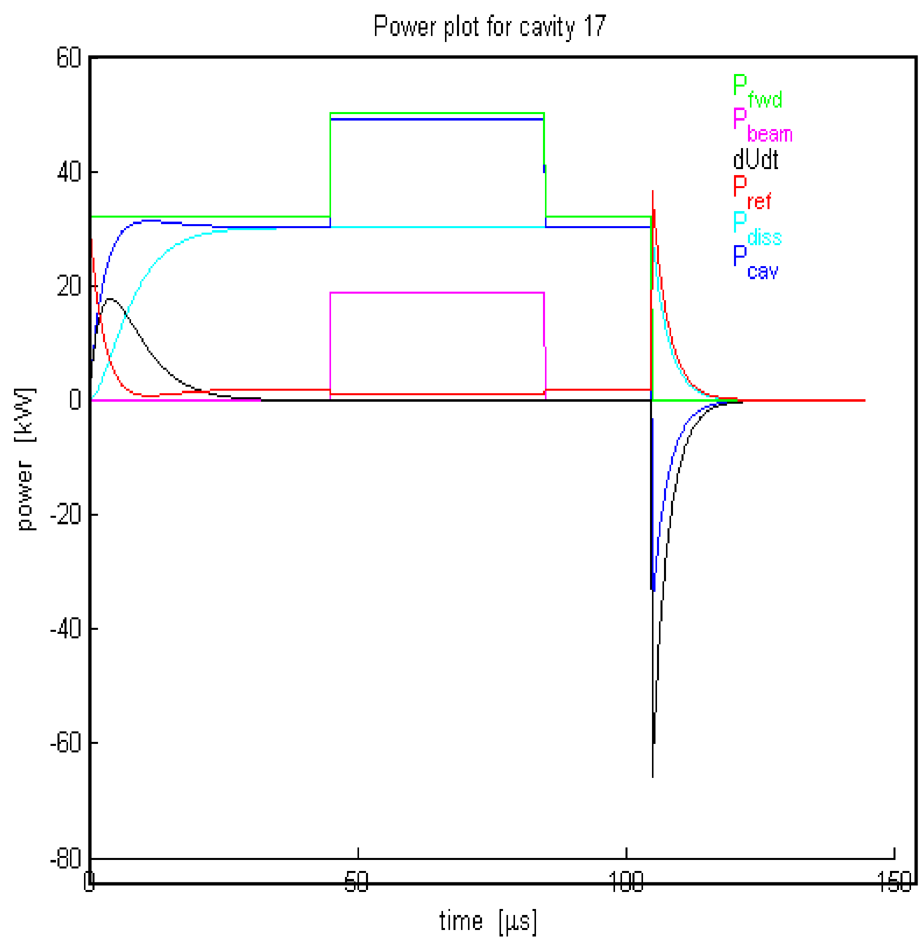
Project X

Beam loading compensation

FF klystron amplitude and phase modulation



Steady state power during beam loading



Power variations during a pulse