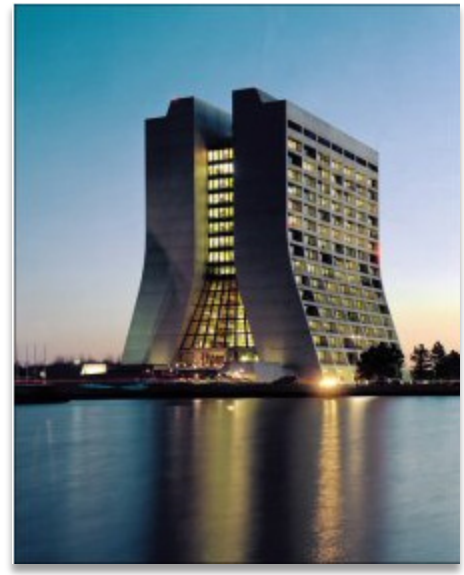
NML CM1 LLRF Overview

B. Chase

June 3rd 2011

FNAL- AD LLRF team



Brian Chase

Barry Barnes

Dan Keplec

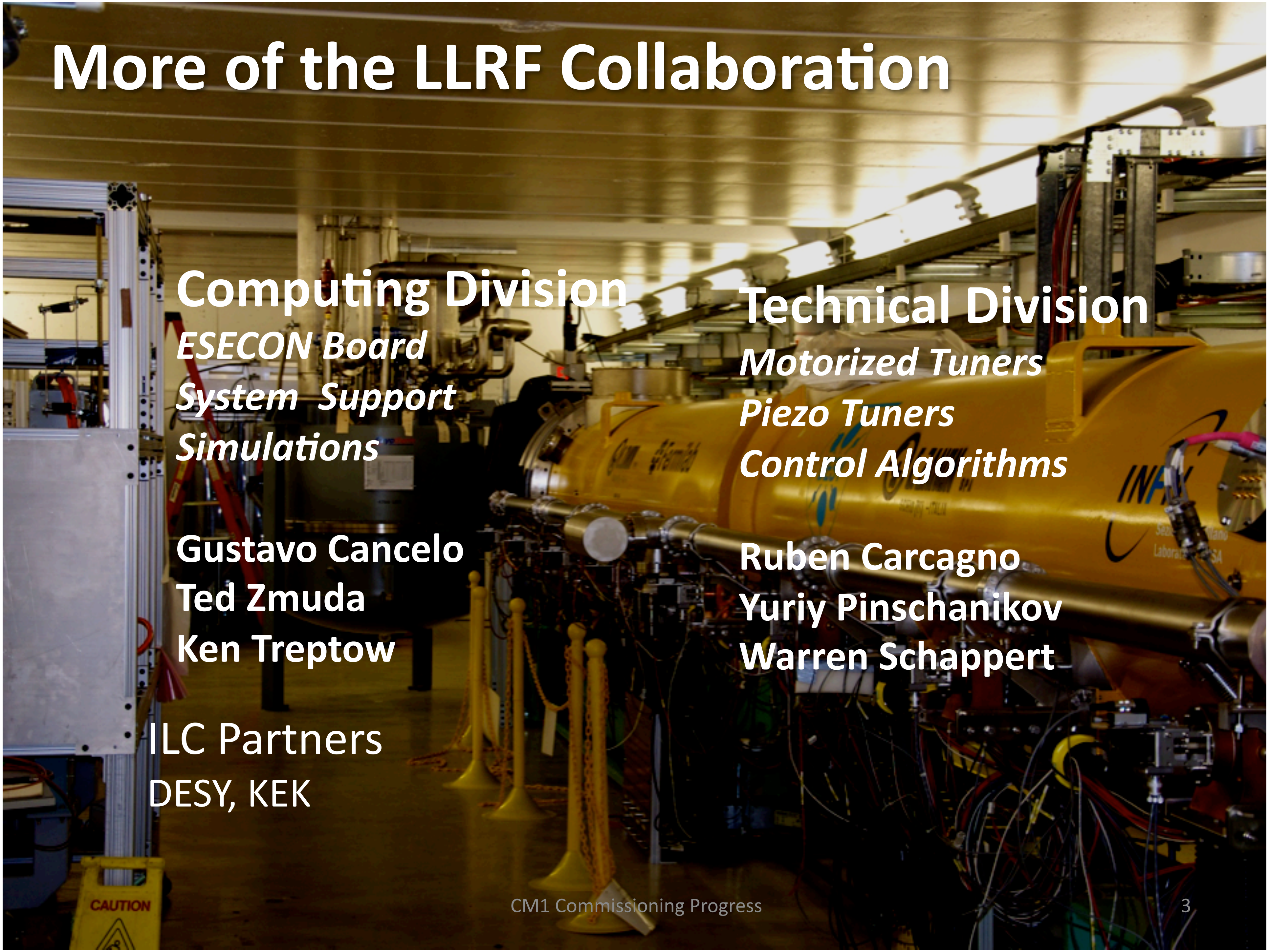
Julien Branlard

Philip Varghese

Ed Cullerton

Vitali Tupikov

Paul Joireman



More of the LLRF Collaboration

Computing Division

ESECON Board
System Support
Simulations

Gustavo Cancelo
Ted Zmuda
Ken Treptow

Technical Division

Motorized Tuners
Piezo Tuners
Control Algorithms

Ruben Carcagno
Yuriy Pinschanikov
Warren Schappert

- ILC Partners
  DESY, KEK

What has been achieved so far ?

- Installed state of the art operational 32 cavity capable LLRF system for CM1
- Operated individually 6 cavities
- Interface to ACNET for control parameters and data logging
- LabView expert operator interface
- RF calibration chain of power couplers, cables and LLRF systems
- Design + test of RF reference line
- LLRF receiver chain stability measurements

Advances for ILC

- FNAL LLRF system provides proof of principle for ILC LLRF
  - Demonstrates all major components (Master Oscillator, Receivers, transmitter, controller, cable plant, external system interfaces)
  - Control includes filter for $8\pi/9$ and $7\pi/9$ modes
  - Exceeds main linac requirements
  - Dramatically reduces costs
- Development of simulators
  - for multi-cavity control (incl. microphonics, LFD, operating gradient spread)
  - HLRF distribution simulation using Agilent ADS
- Numerous built-in diagnostics
  - (i.e. Live FFT display of any test point)
- Cavity control performance (open and close loop)
  → see performance picture slide (at the end)
- Training of next generation of RF scientists and engineers with the intangible value of direct experience

NML CM1 LLRF Racks

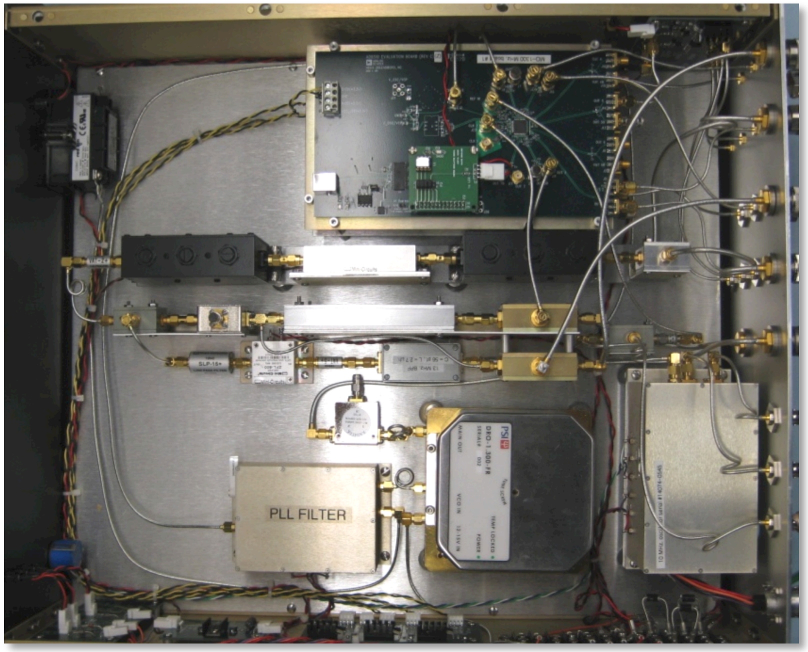
Receivers and Up-converters

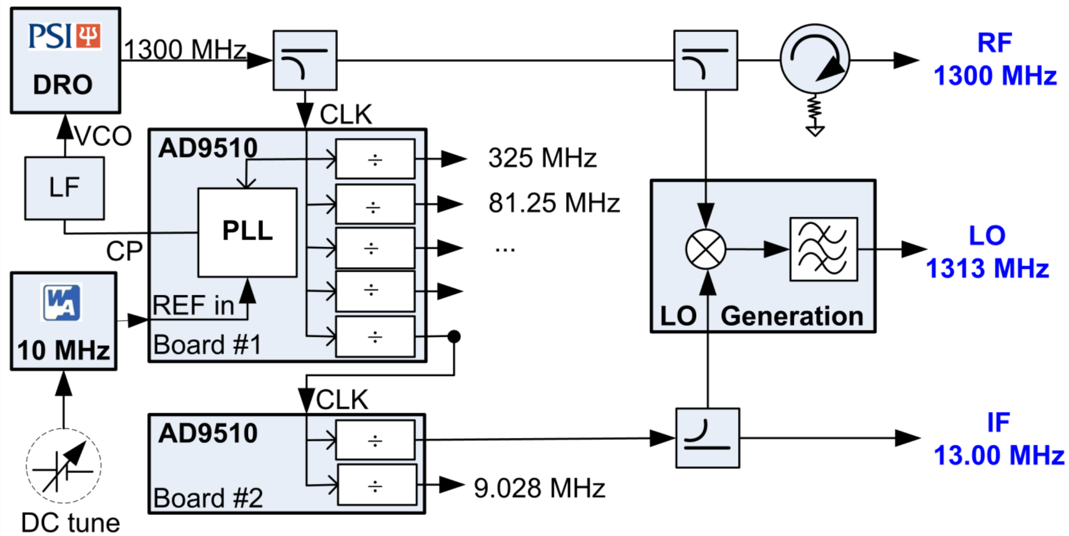
VXI CPU &
3 R3MFC Controllers

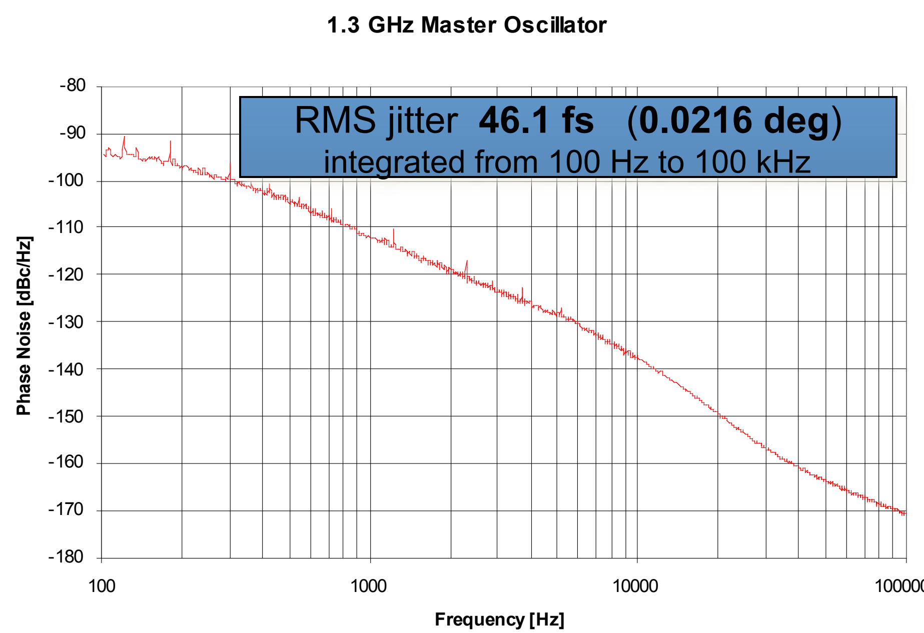
Master Oscillator

Power Supplies

Master Oscillator

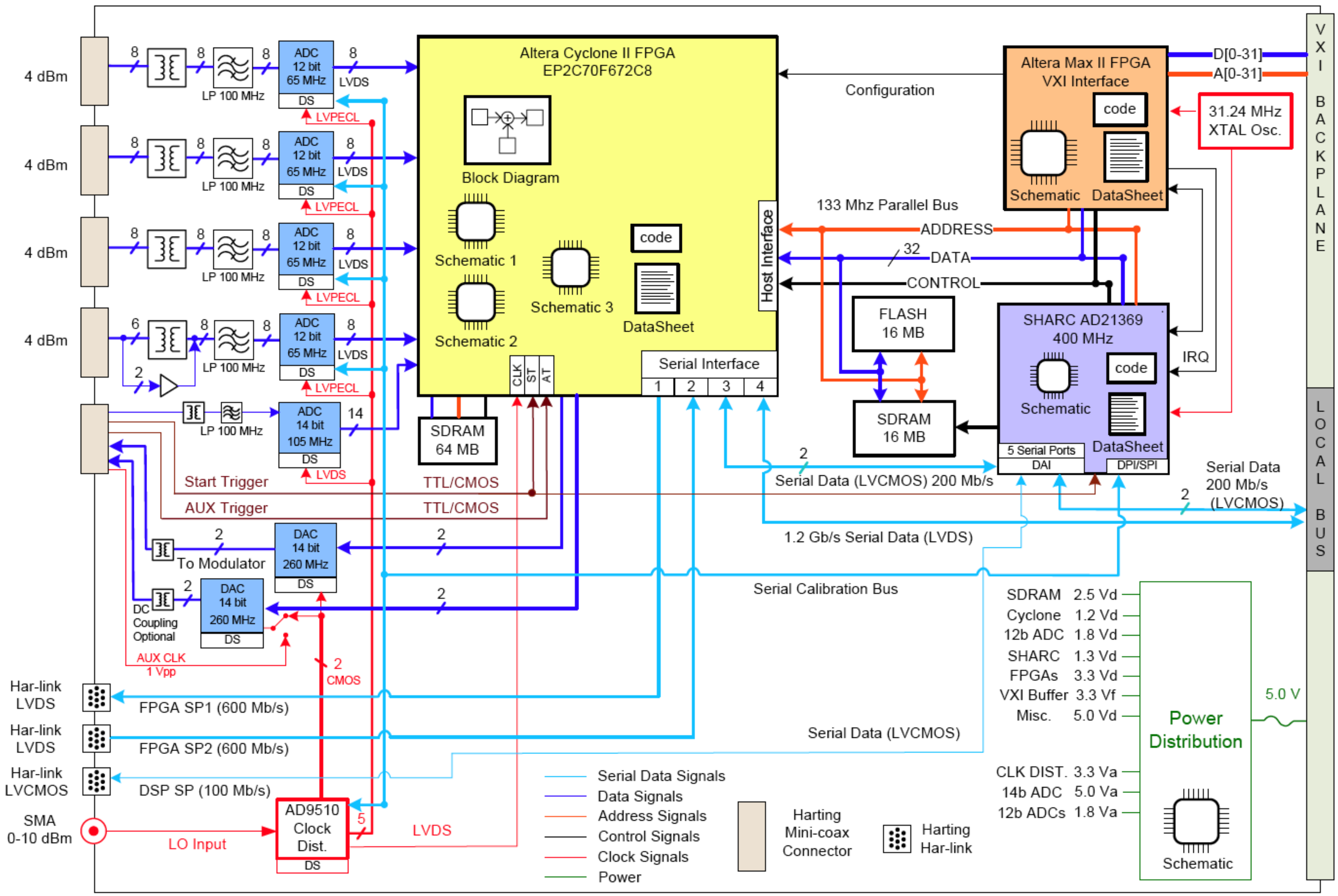




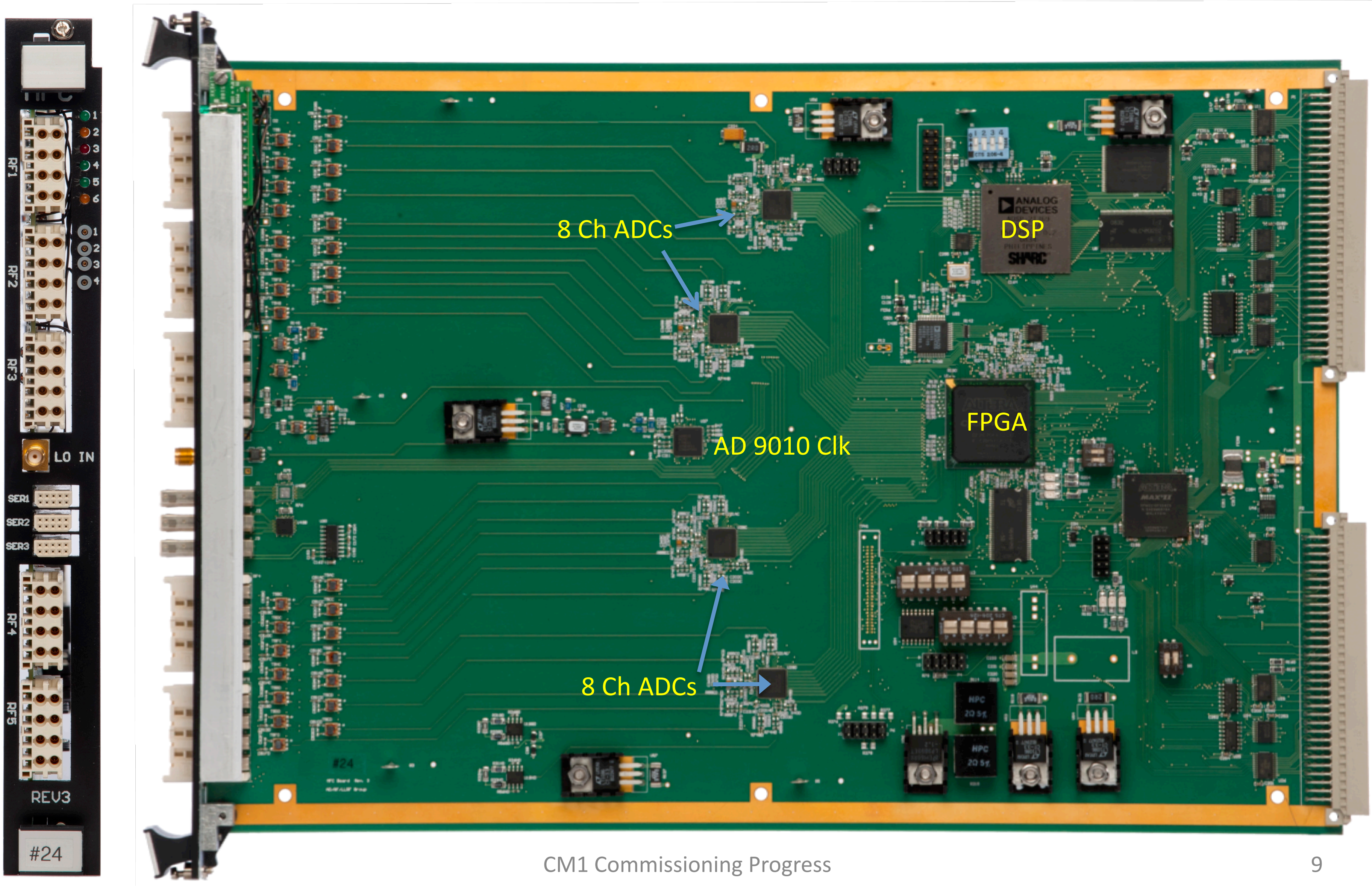


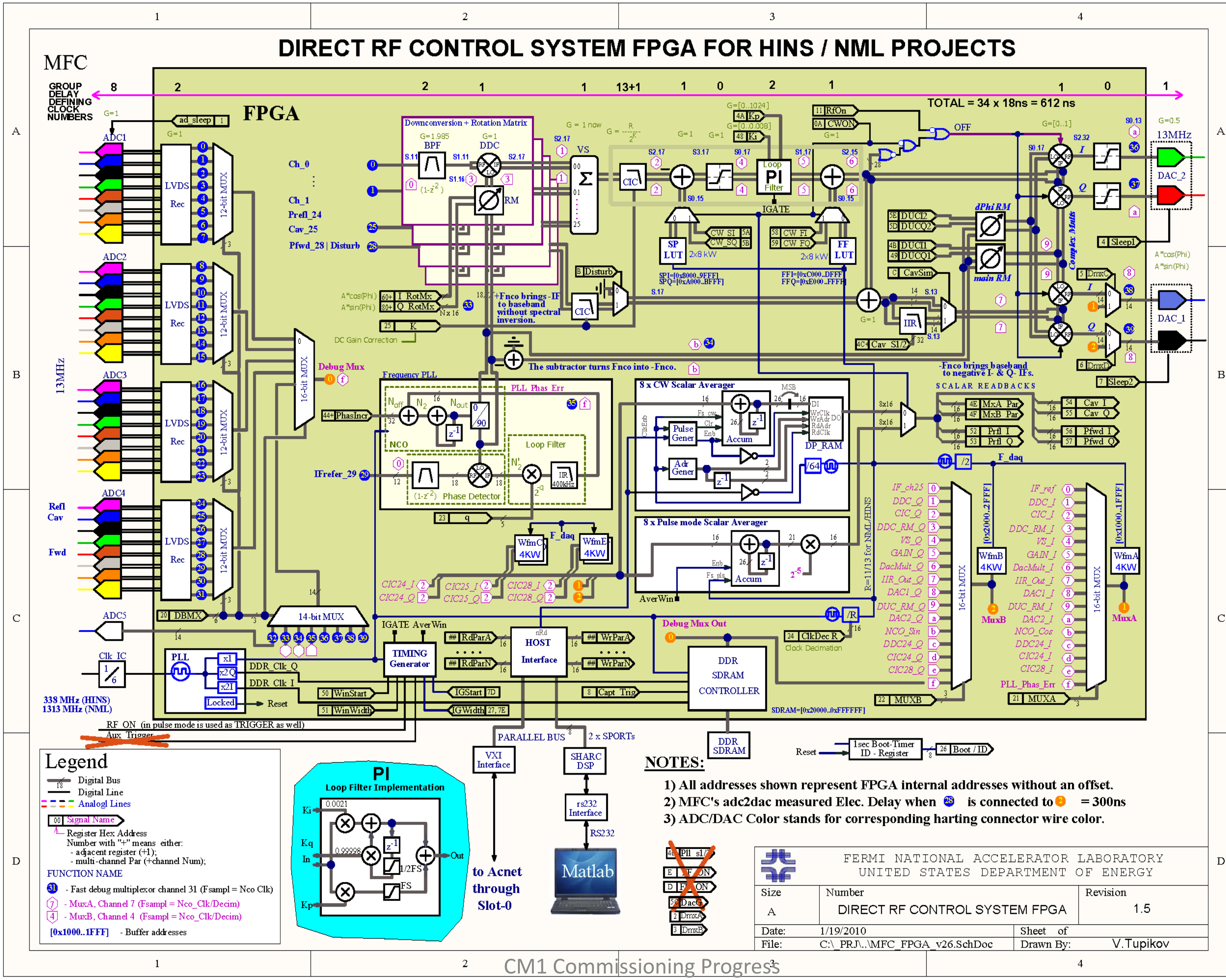
- RF, LO, IF
- Programmable outputs
- Timing reference
- 1.3 GHz
- <140 fs integrated jitter (1Hz–10MHz)

33 Channel Controller (MFC)



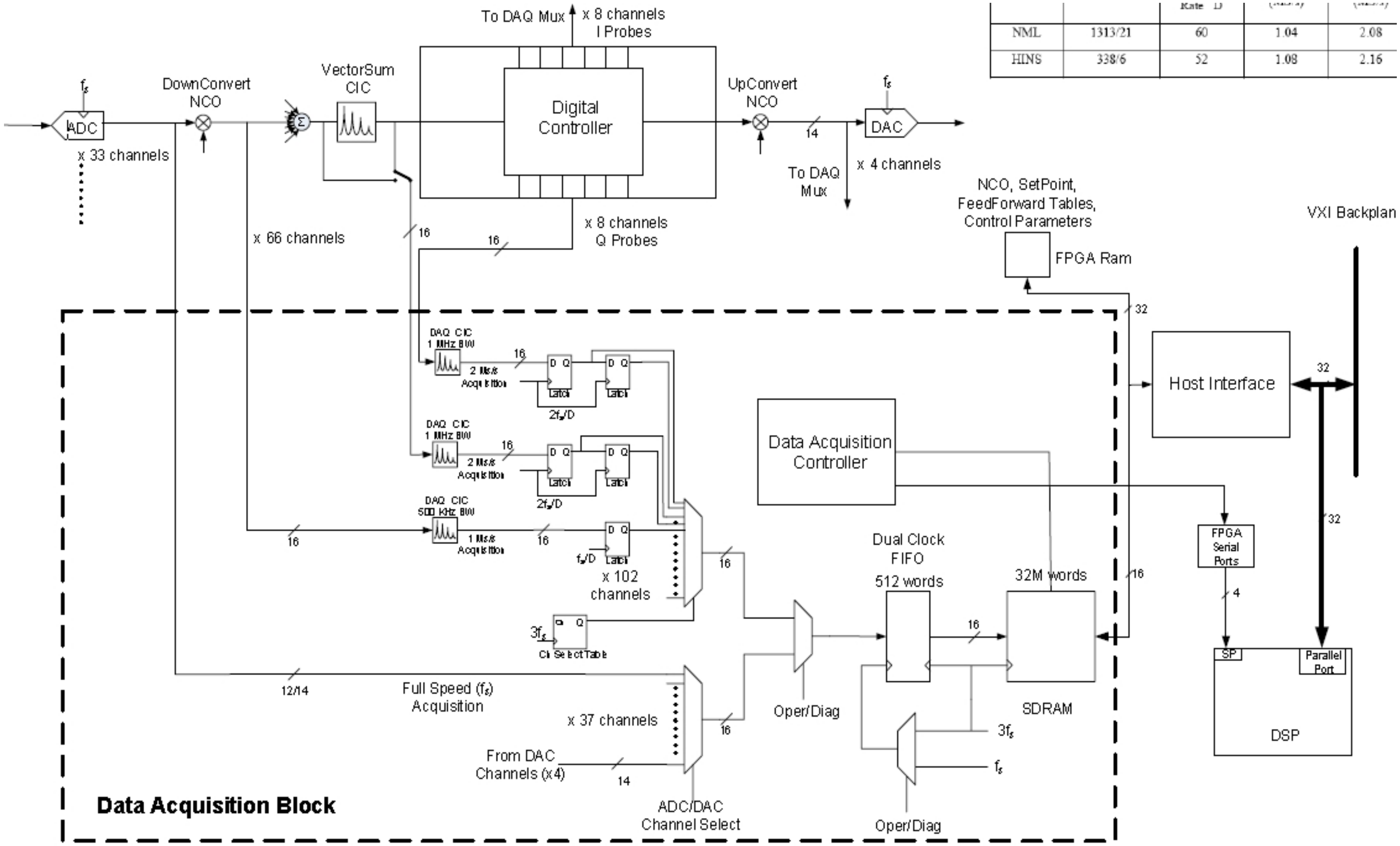
R3-MFC Circuit Board



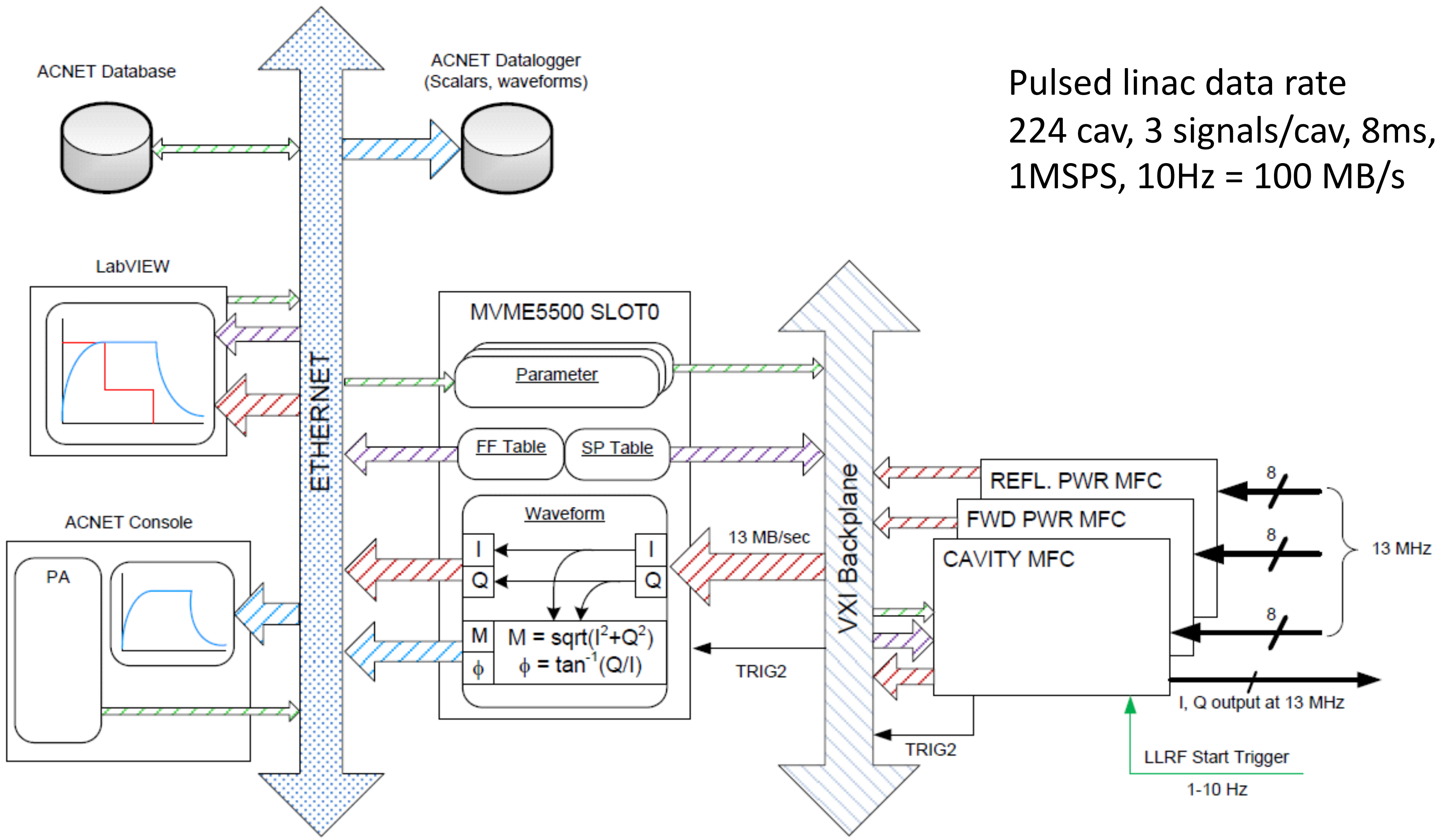

DIRECT RF CONTROL SYSTEM FPGA FOR HINS / NML PROJECTS
MFC
GROUP DELAY DEFINING CLOCK NUMBERS
TOTAL = 34 x 18ns = 612 ns
FPGA
Downconversion + Rotation Matrix
Frequency PLL
8 x CW Scalar Averager
8 x Pulse mode Scalar Averager
SCALAR READBACKS
14-bit MUX
TIMING Generator
HOST Interface
DDR SDRAM CONTROLLER
DDR SDRAM
PARALLEL BUS
2 x SPORTs
VXI Interface
SHARC DSP
rs232 Interface
RS232
Matlab
to Acnet through Slot-0
PI
Loop Filter Implementation
Legend
Digital Bus
Digital Line
Analog Lines
Signal Name
Register Hex Address
Number with "+" means either:
- adjacent register (+1);
- multi-channel Par (+channel Num);
FUNCTION NAME
- Fast debug multiplexor channel 31 (Fsampl = Nco Clk)
- MuxA, Channel 7 (Fsampl = Nco_Clk/Decim)
- MuxB, Channel 4 (Fsampl = Nco_Clk/Decim)
[0x1000..1FFF] - Buffer addresses
NOTES:
1) All addresses shown represent FPGA internal addresses without an offset.
2) MFC's adc2dac measured Elec. Delay when 28 is connected to 2 = 300ns
3) ADC/DAC Color stands for corresponding harting connector wire color.
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
Size A
Number DIRECT RF CONTROL SYSTEM FPGA
Revision 1.5
Date: 1/19/2010
File: C:_PRJ\..\MFC_FPGA_v26.SchDoc
Sheet of
Drawn By: V.Tupikov

Firmware – DAQ
Flexible and Programmable

NML	1313/21	60	1.04	2.08
HINS	338/6	52	1.08	2.16

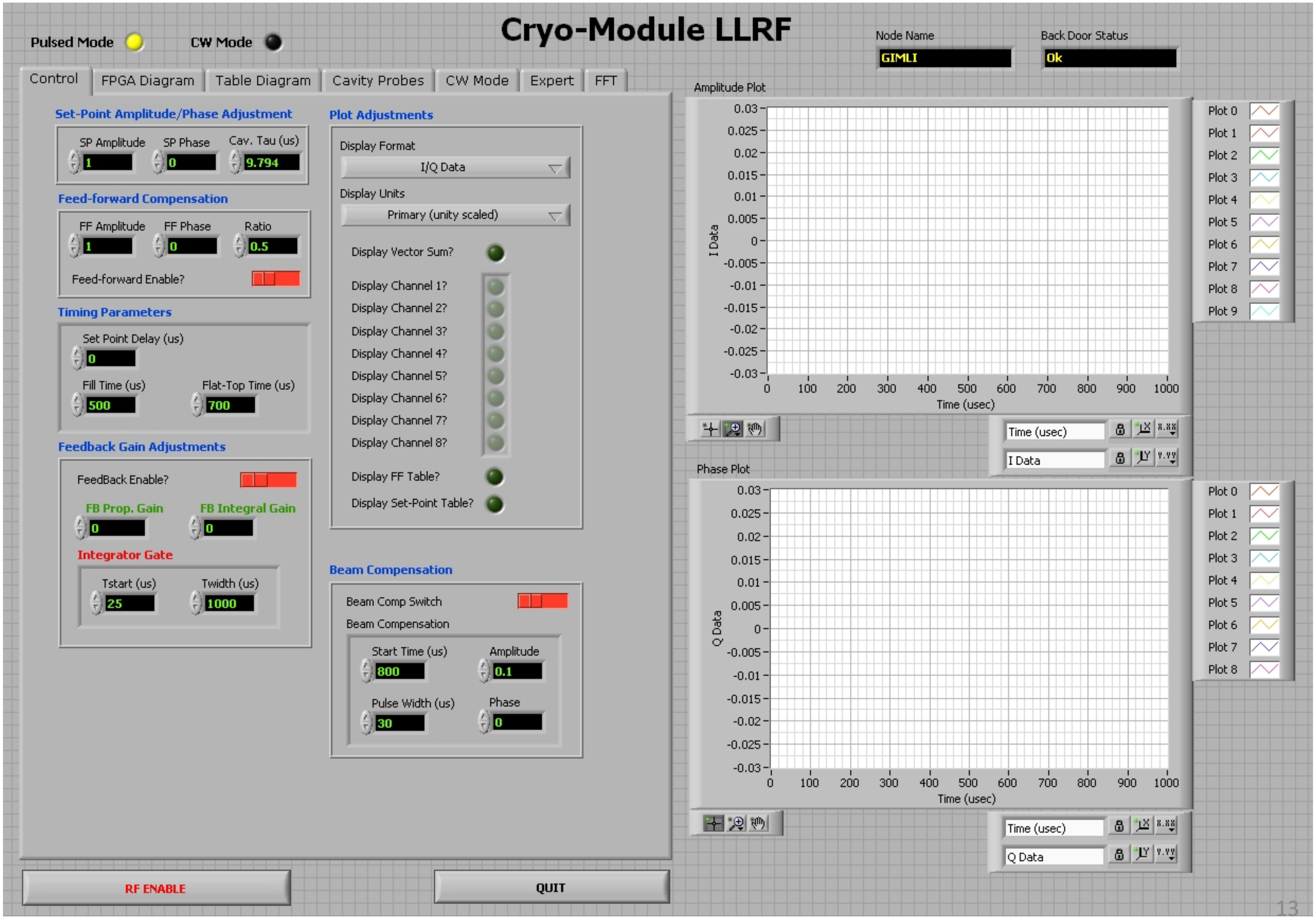


LLRF Data Flow Diagram



Pulsed linac data rate
224 cav, 3 signals/cav, 8ms,
1MSPS, 10Hz = 100 MB/s

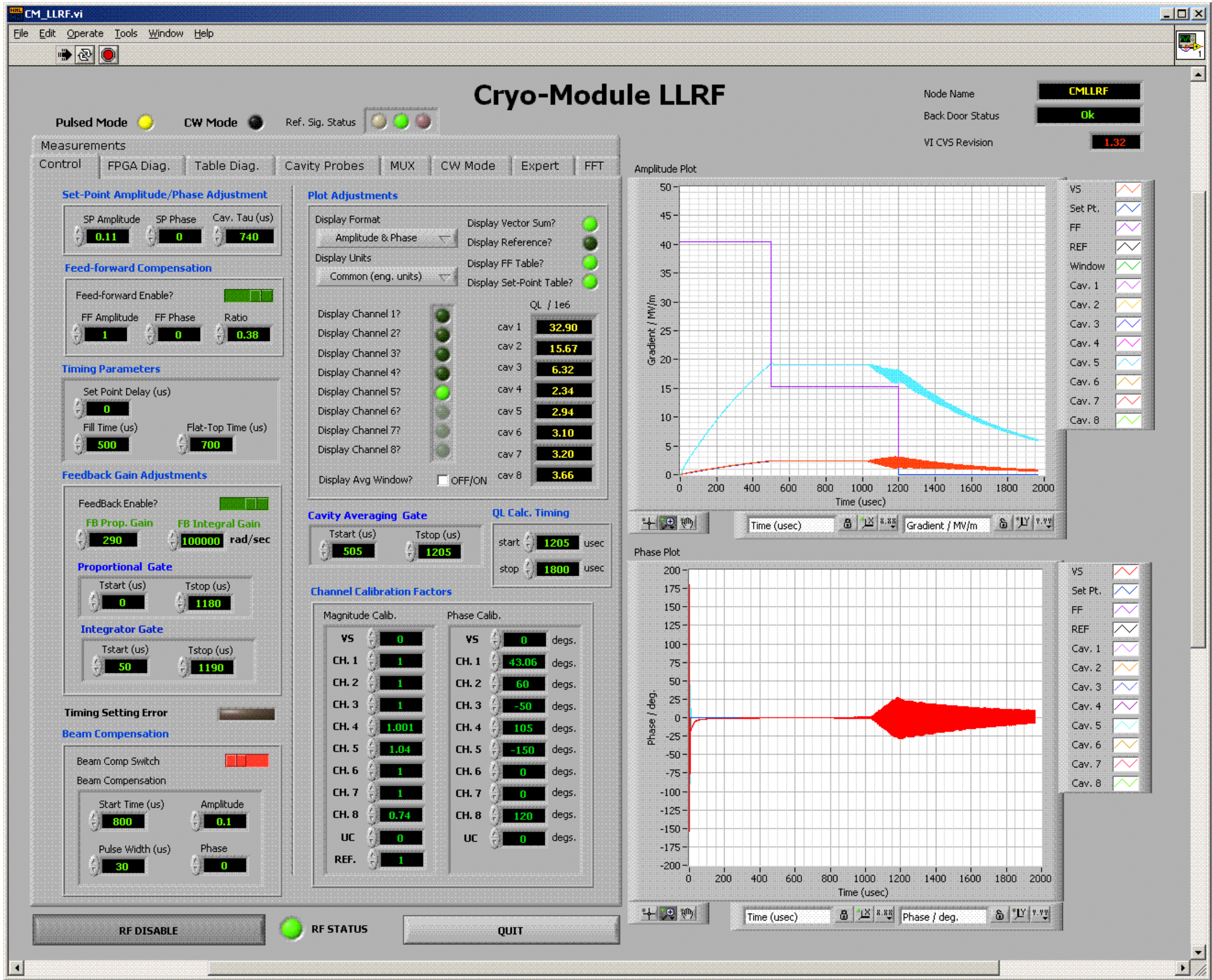
LabView Operator Interface



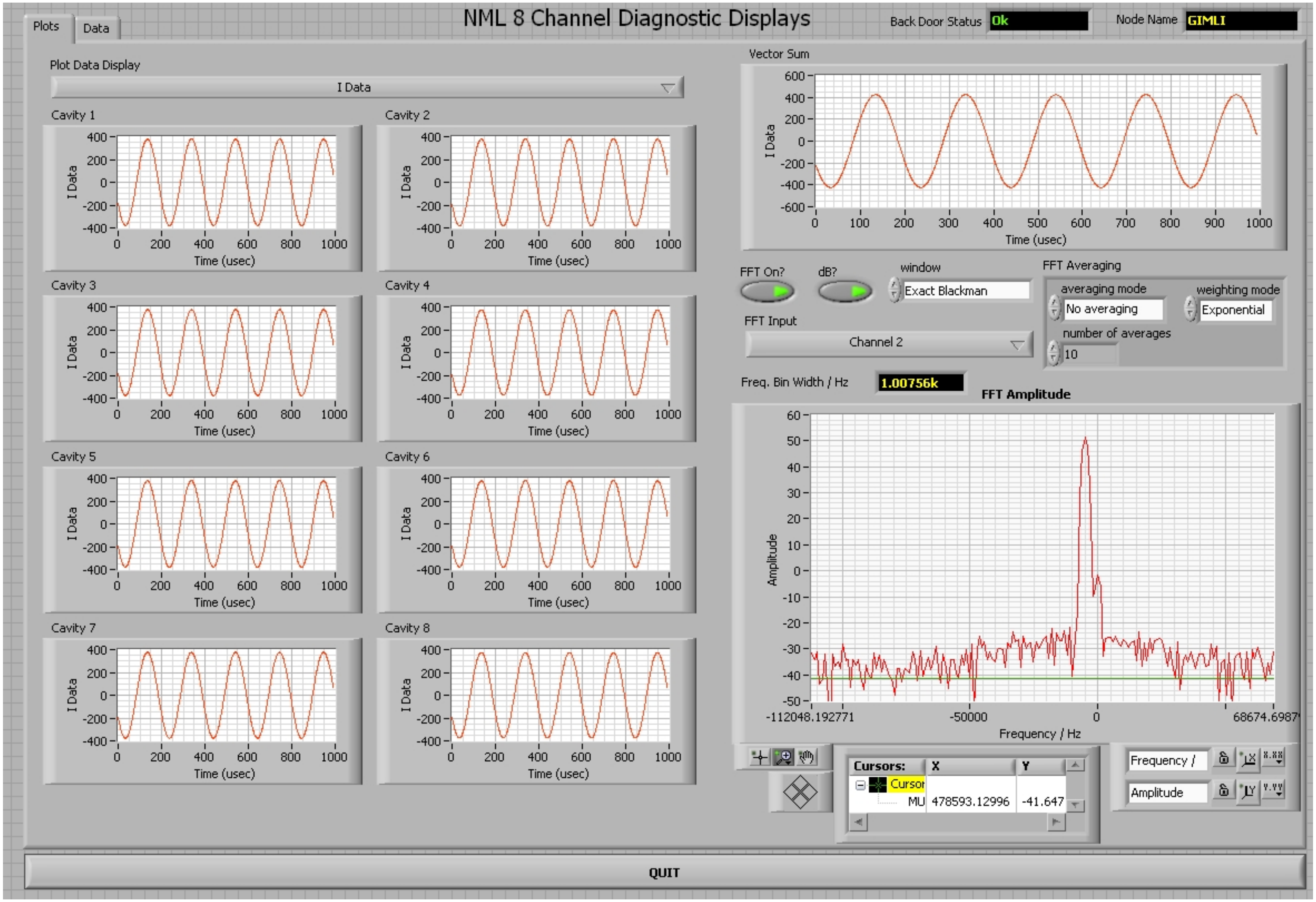
LabView Operator Interface

- Closed loop operation with 8pi/9 mode uncontrolled

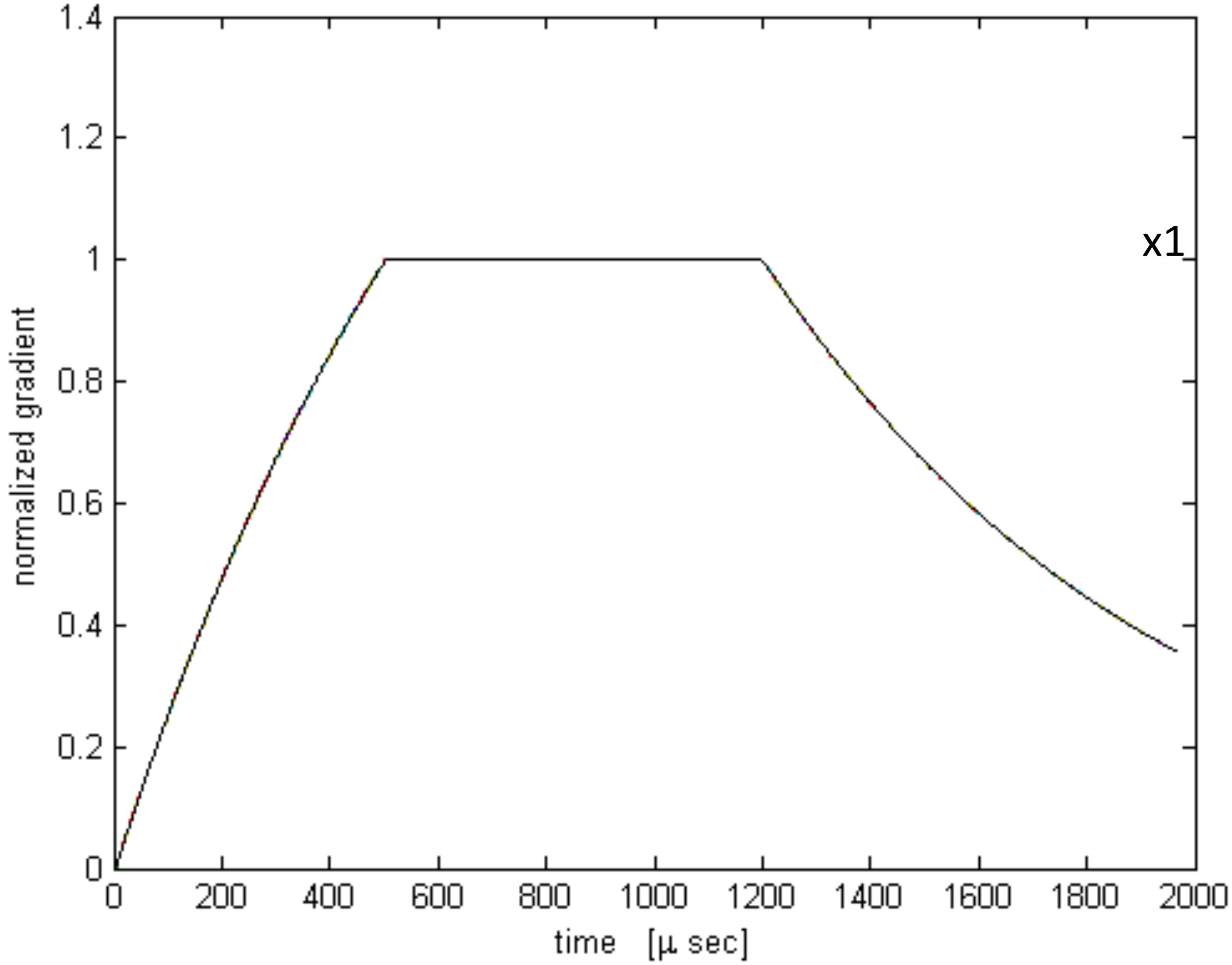
- Top level control page



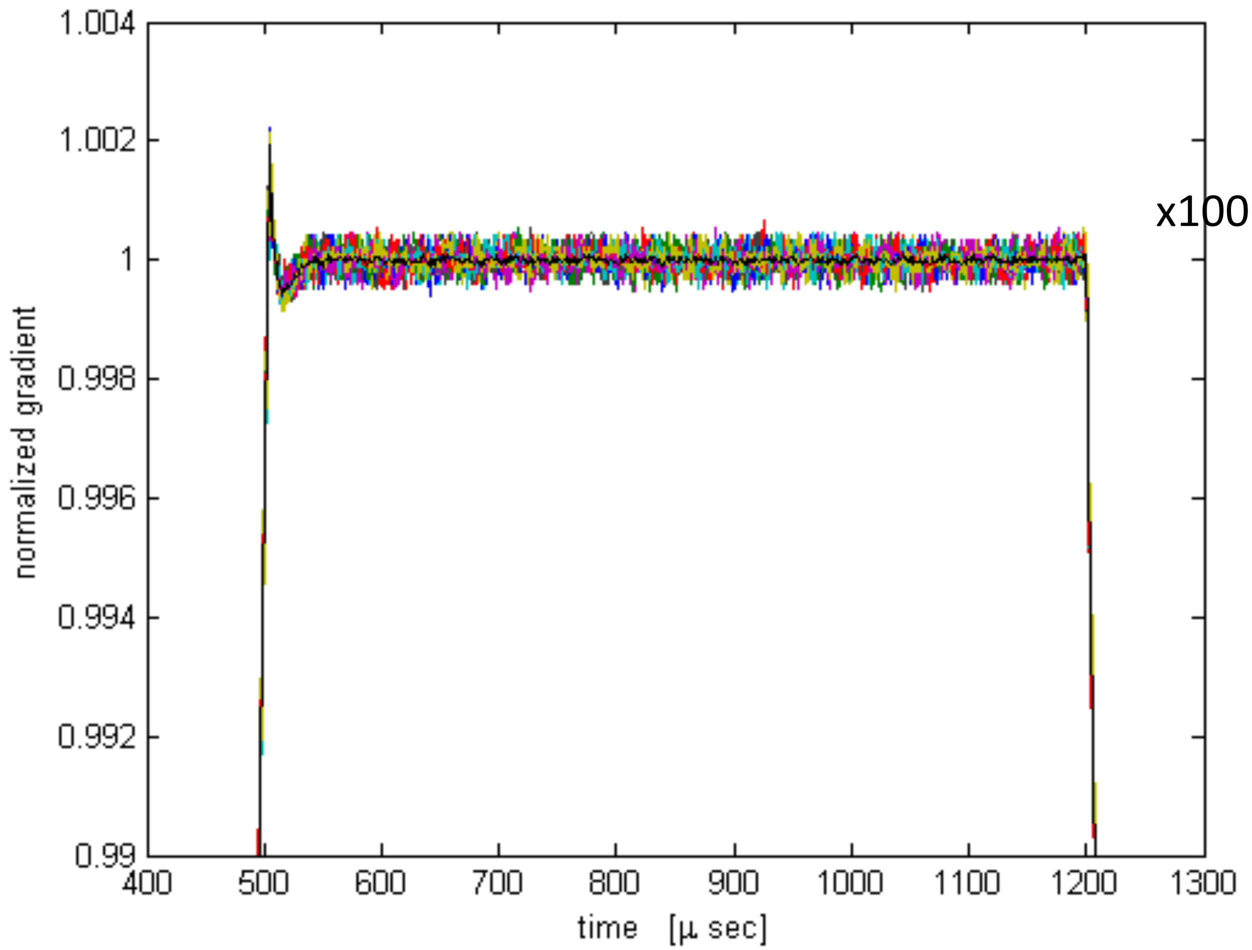
Individual Cavity and FFT Display



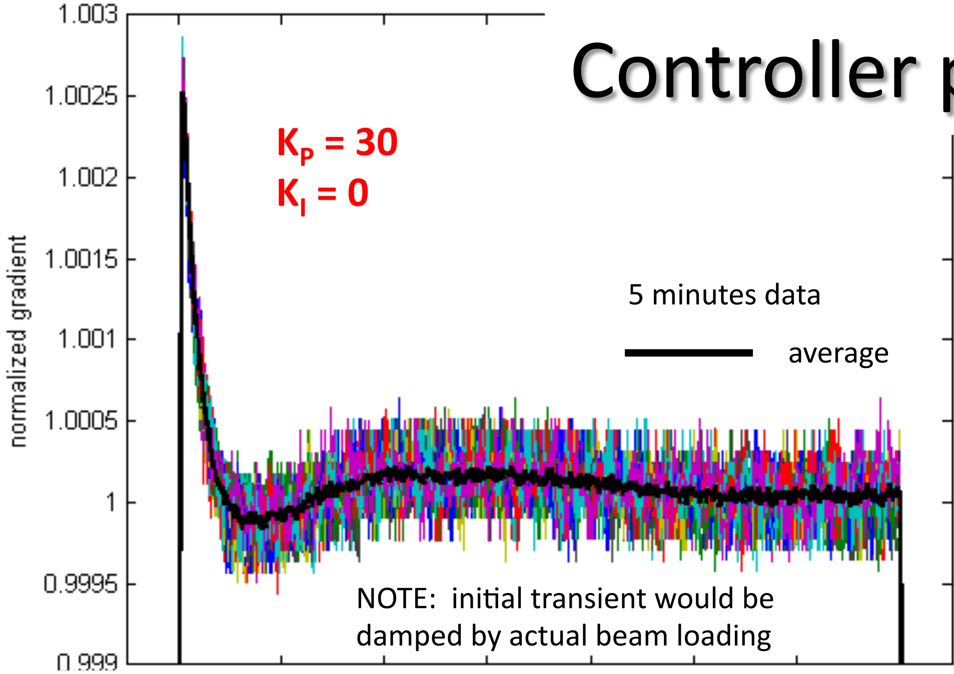
Amplitude waveform Under Regulation

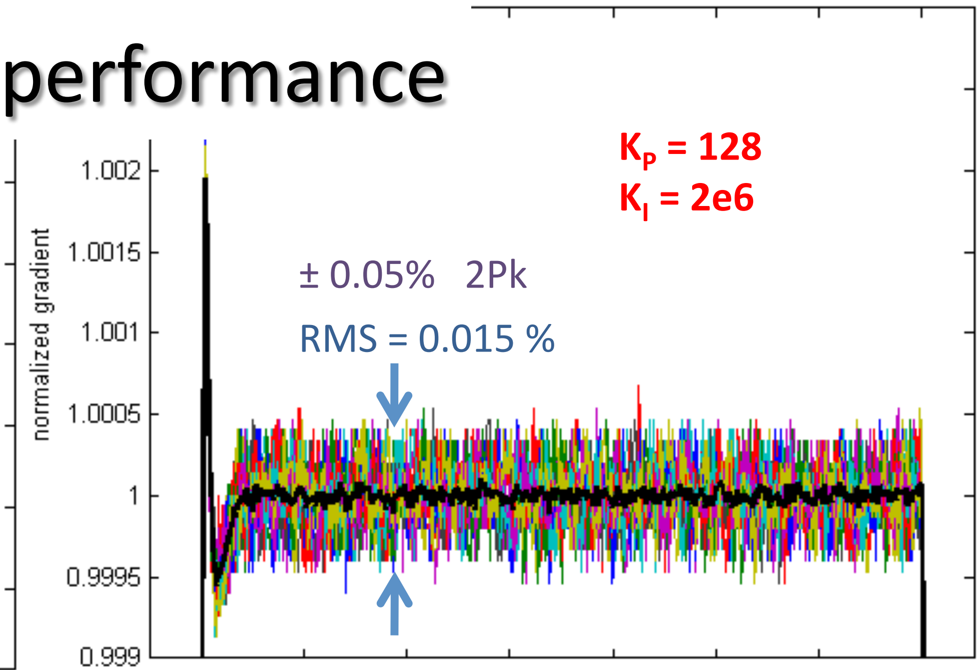


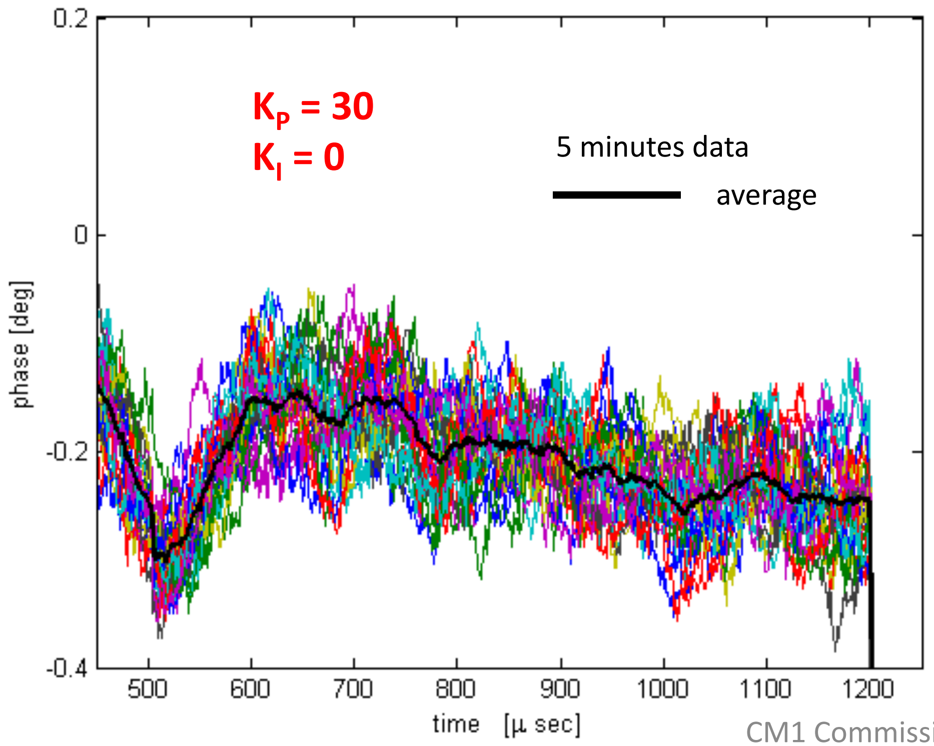
Zooming on the flat top regulation x100

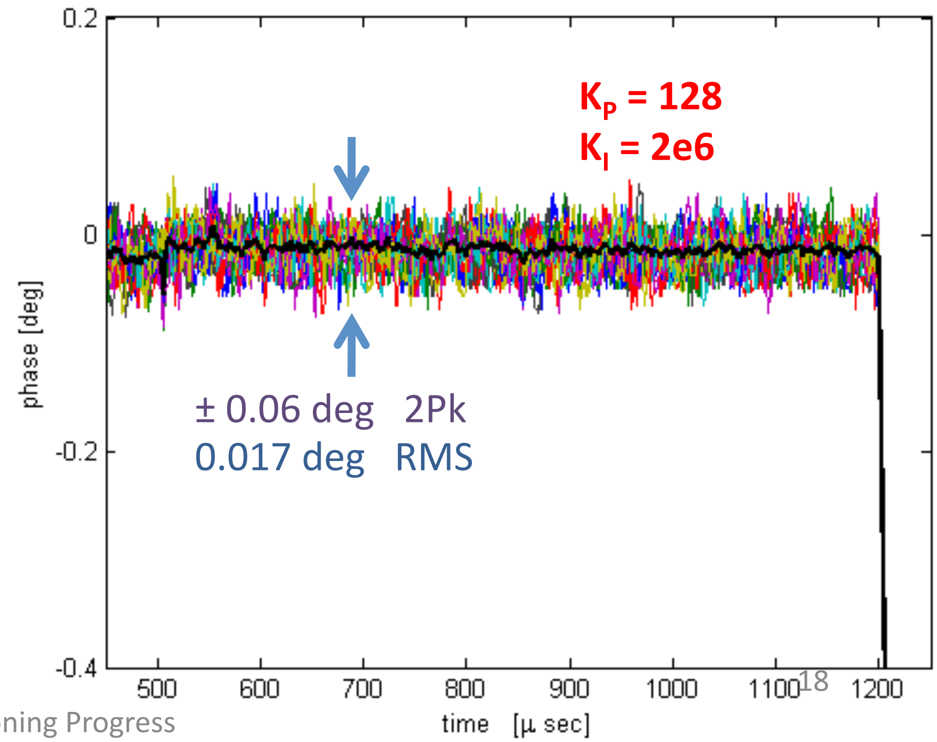


Controller performance



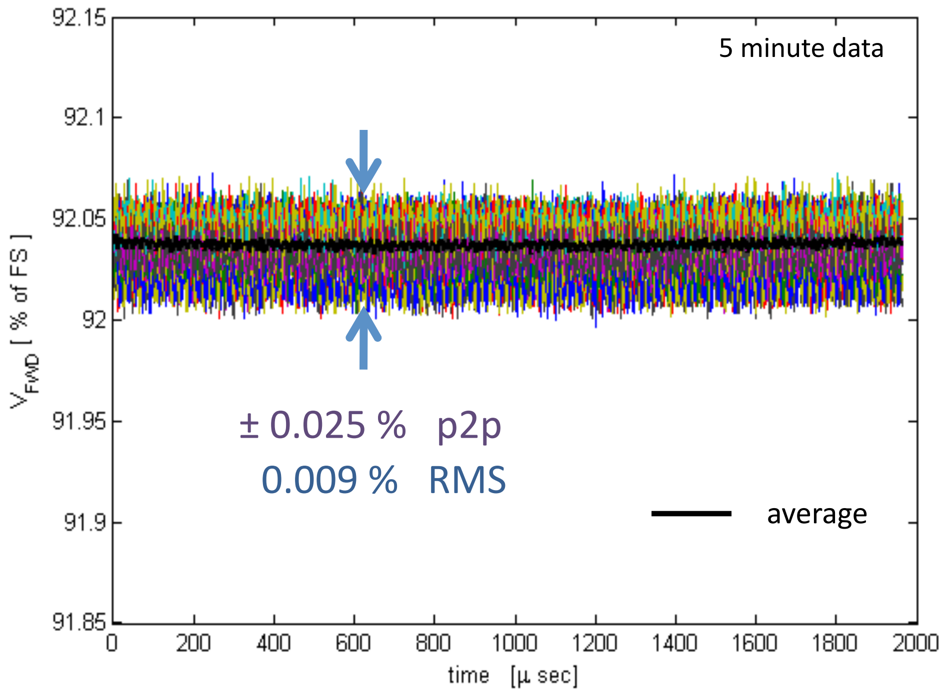




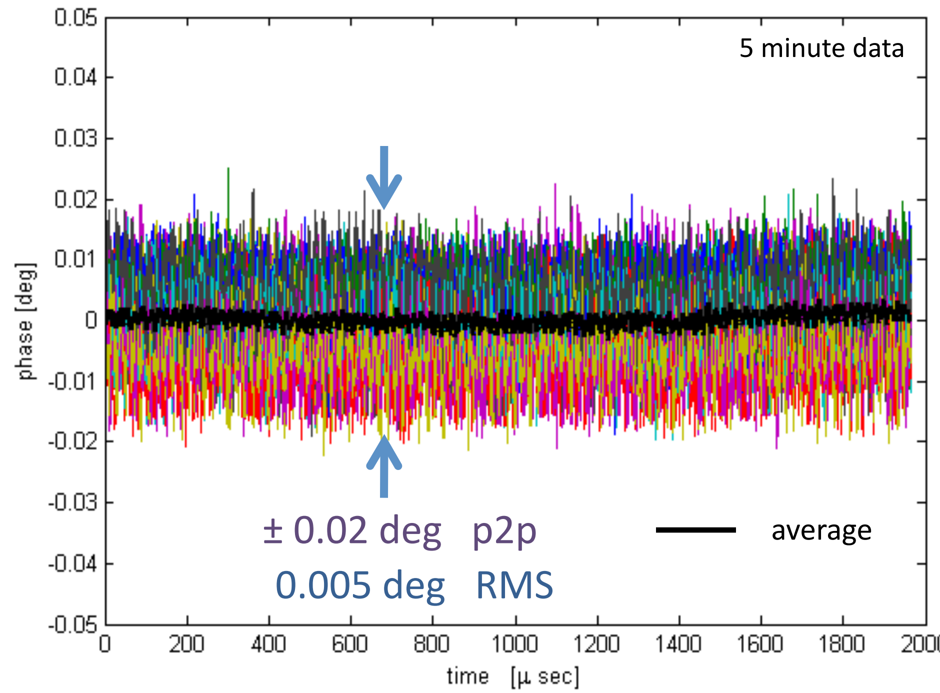


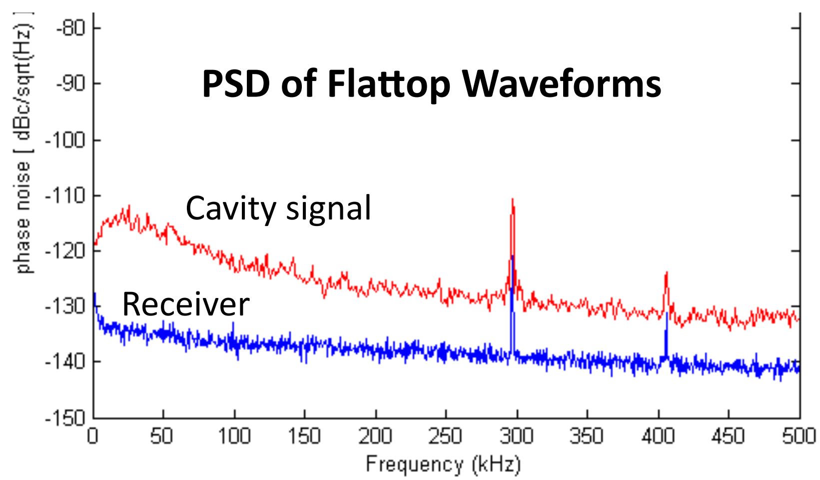
Receiver noise

Amplitude

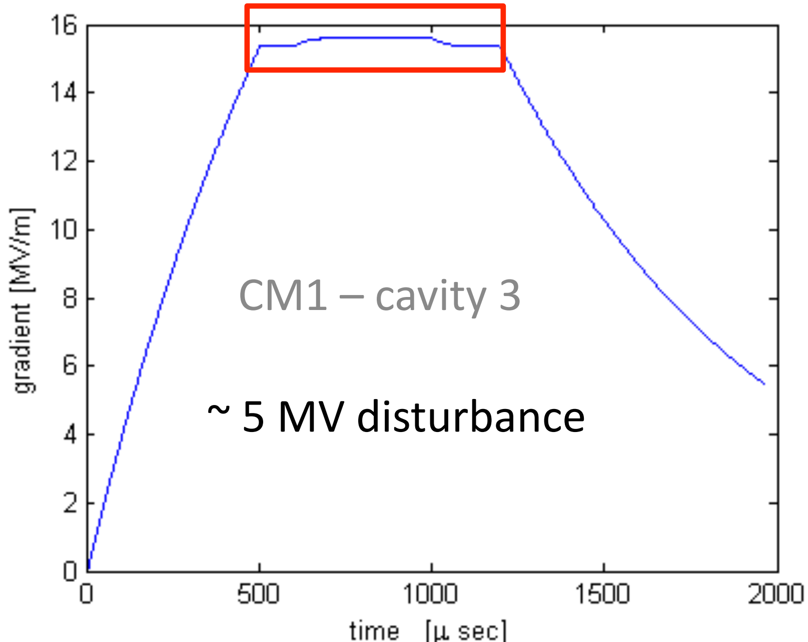


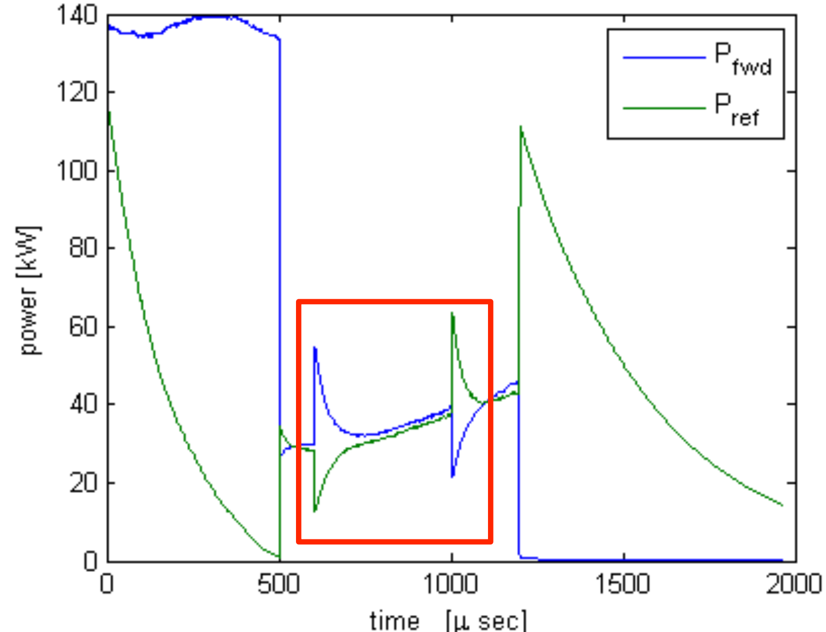
Phase

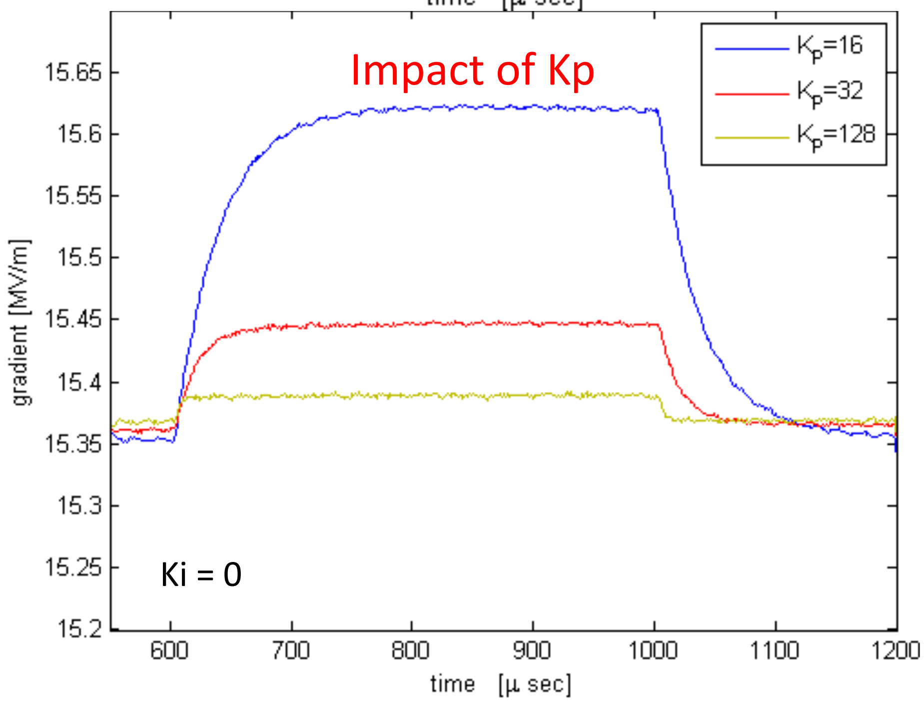


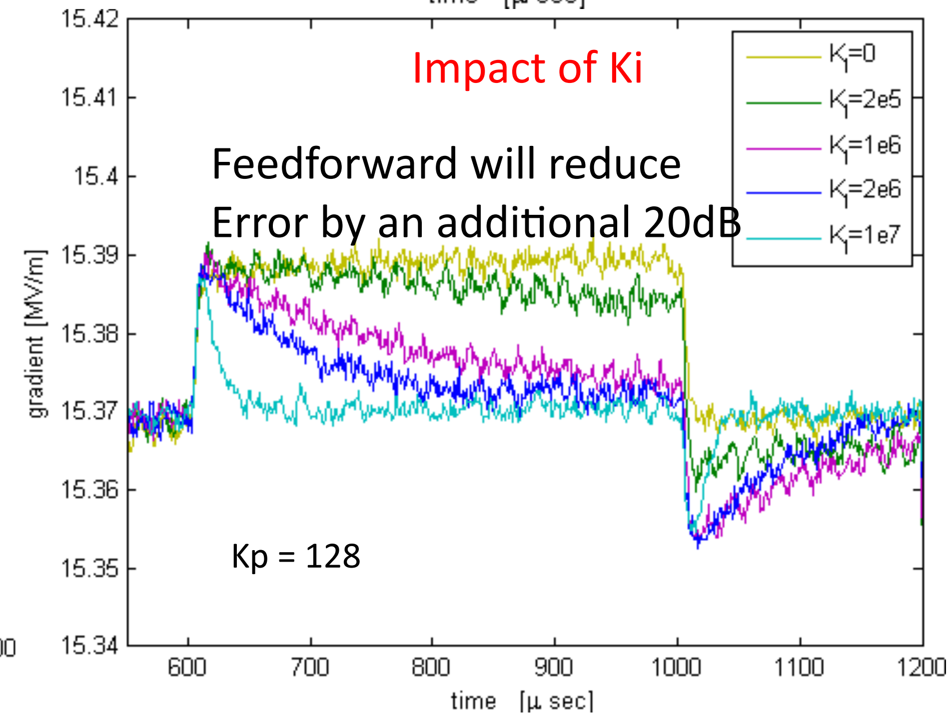


Perturbation analysis

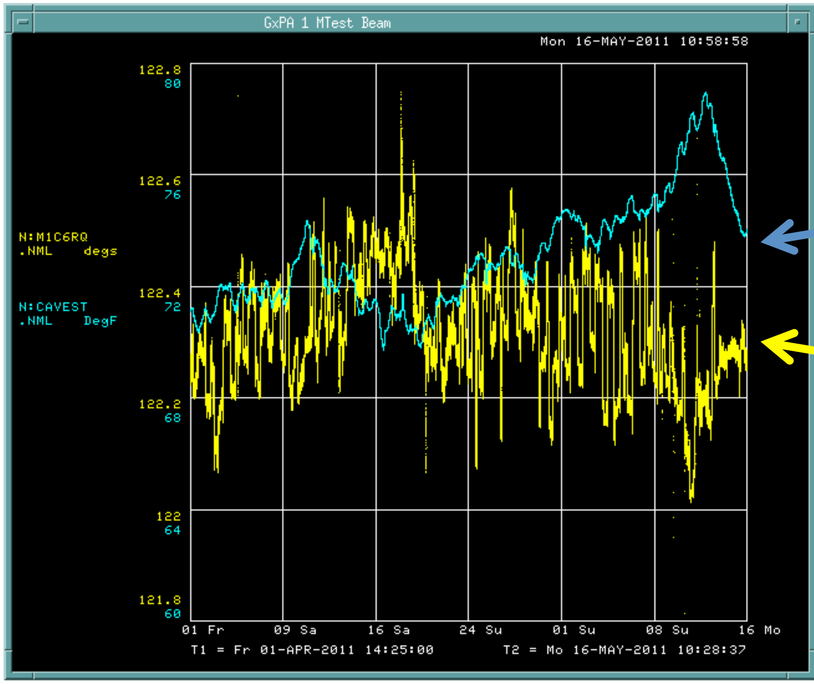








Receiver Chain Stability Measurement vs Building Temperature



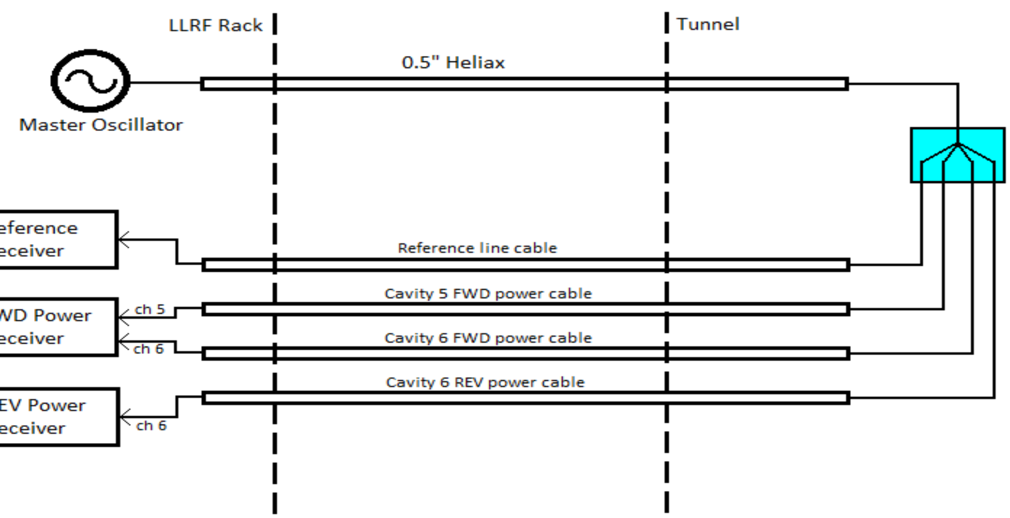
Blue – Building Temperature

Yellow – CH 6 Rev phase

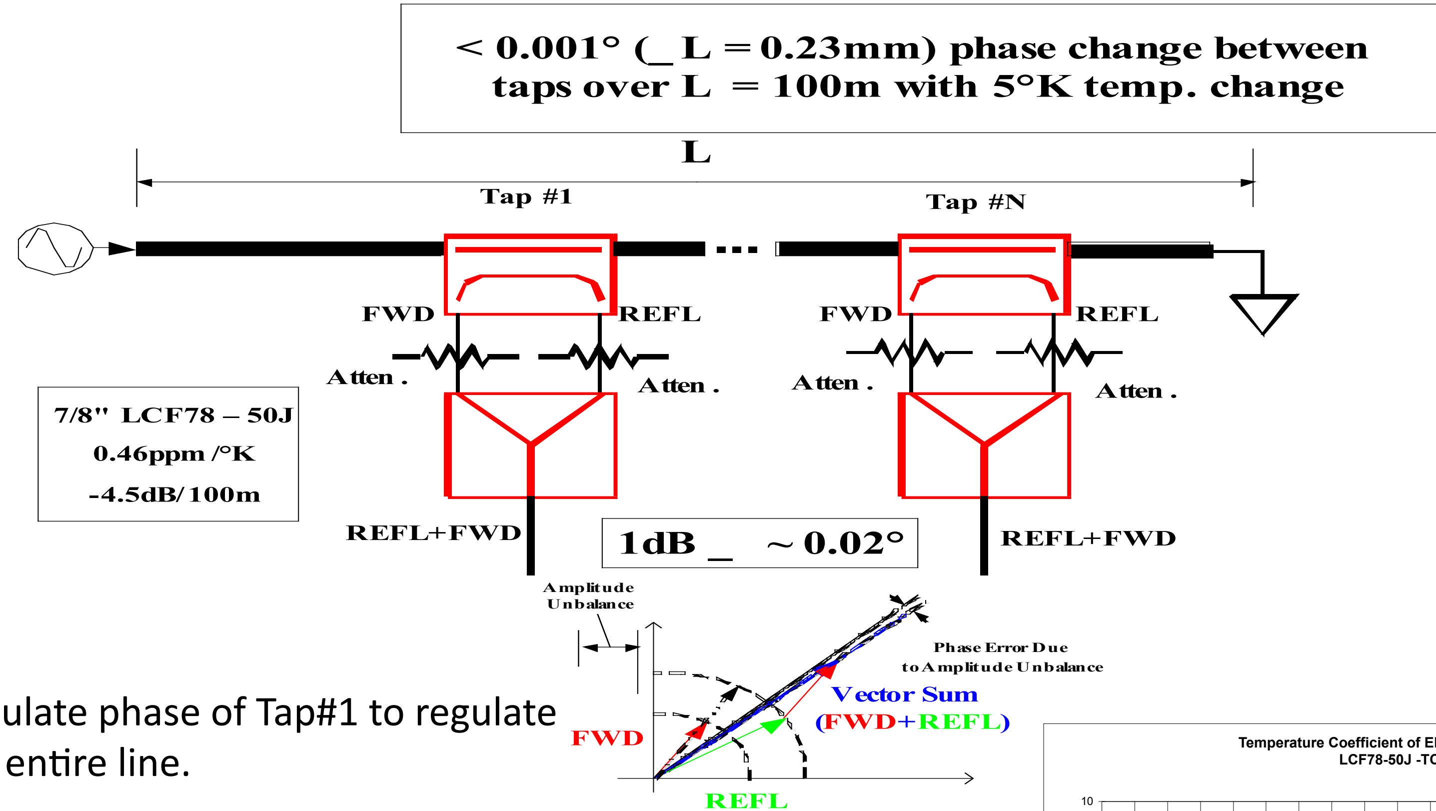
6 week test period

Approximate phase variation = 0.03 degrees / 1 degree F

Receiver chain phase variation test set-up

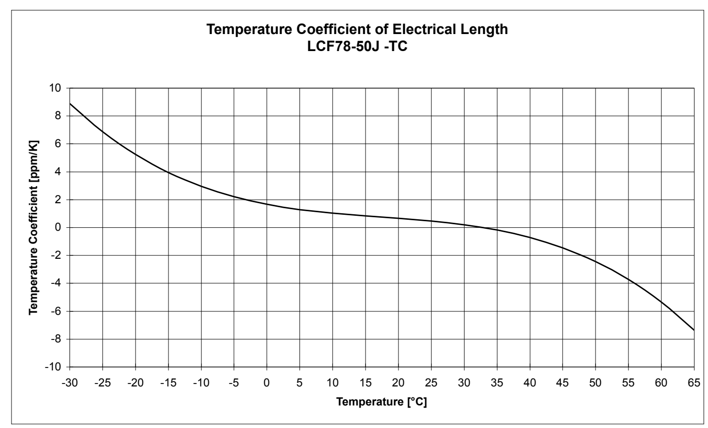


High Stability Reference Line



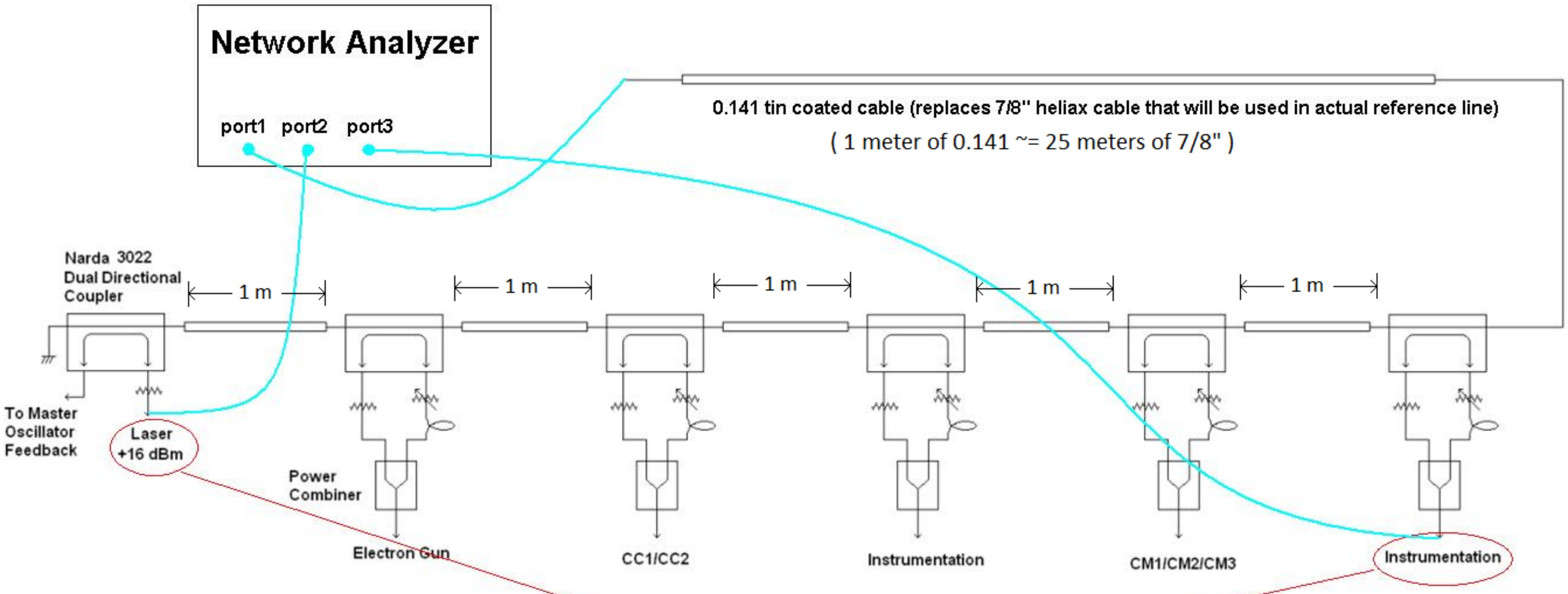
Regulate phase of Tap#1 to regulate the entire line.

Control by phase shift of forward power or temperature control of Line.

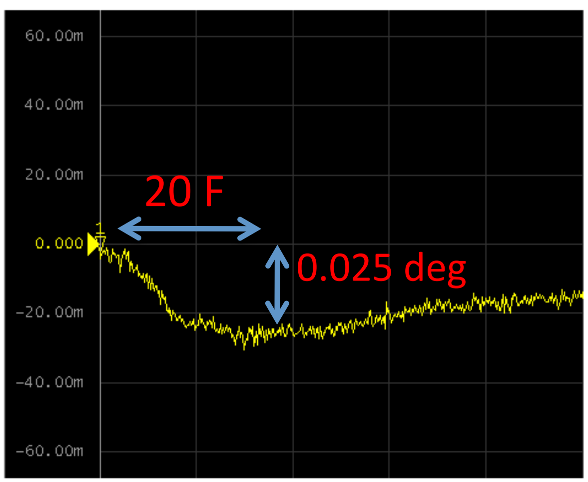


Lab Measurements of Phase Averaging Reference Line

Beams docDB # 3806-v1



Phase difference between Laser port and Instrumentation port over a 20 degree temperature change (85 - 105 deg F)



* Measured in the lab using a network analyzer in a temperature controlled oven.

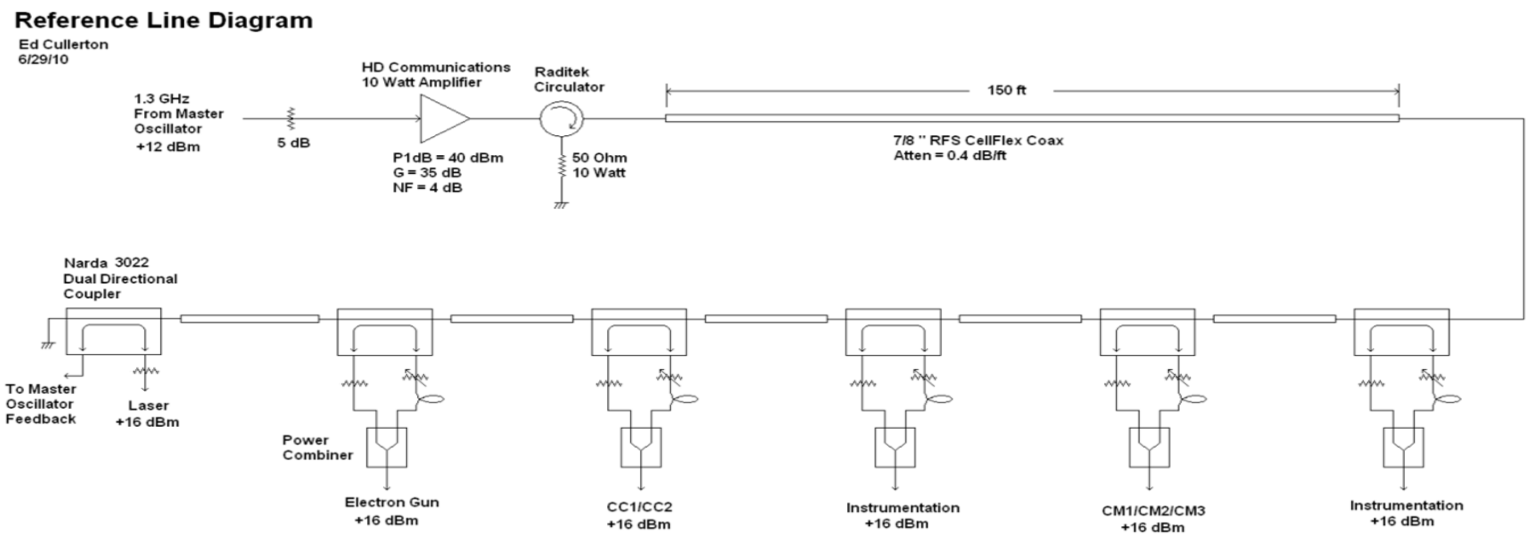
* Long sections of 7/8 " RFS cable replaced with short sections of tin coated .141 cable that has similar temperature characteristics.

* Measurement may have small uncertainty due to calibration drift of the network analyzer.

* Oven temperature ramped from 85 to 105 degrees F in first twenty minutes of measurement.

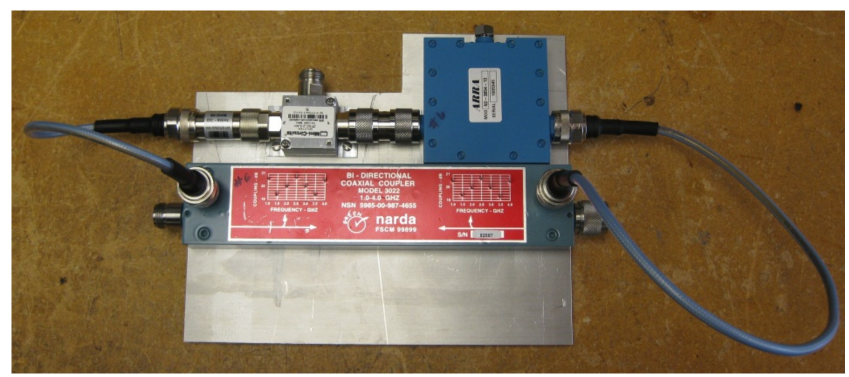
* Total measurement time is 1 Hour

Reference Line Cost Analysis



30 M section for 1 RF station:
1 directional coupler $700
1 power combiner $30
1 variable attenuator $200
1 fixed attenuator $20
30 meter section of RFS 7/8” cable $200
2 ft of times Microwave phase track cable ... $50
1 mounting plate and hardware $250
1 heater control circuit and power supply $250

Total hardware cost per tap $1700
Cost per meter..$57



What are the issues ?

- Obtaining flat gradient and phases in multicavity operation
- “N” different $8\pi/9$ and $7\pi/9$ mode frequencies
  - Large observed spread in frequencies
- Understanding limitations of weak performing cavities (Q_0 drop)
- Operation with spread in cavity gradients

What are the improvements we are looking to make in the future ?

- Resonance control integration into LLRF system
- Cryomodule level full vector sum control
  - Ready for 24 cavities (3 cryomodules)
- Installation of RF reference line
- Resume operation of CCII
- Quench detection & recovery algorithm
- Long term stability/operability studies
- Prepare for gun operations (Beam)
  - Beam based calibration
  - Operation with gradient spreads