Timing: Precision Beam Timing

FAC Meeting Nov 12, 2008

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Timing Requirements

- For pump / probe experiments need to synchronize experimenters' lasers to the X-rays
  - Want timing stability < RMS pulse width
  - 30 femtosecond RMS (normal operation)
  - Could need 2 femtoseconds in ultra-short bunch mode (Discussed today breakout 1,2 15:20)
- Time-constant for drift is “scan time” in experiment (seconds to days???)

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System Components

- Phase distribution system
  - LBNL phase stabilized fiber system
- Beam phase reference
  - Original plan to use electro-optical system
  - Decision to use phase cavity
- X-ray timing
  - Not perfectly locked to the electron beam time
  - Hope for future direct optical – to – X-ray timing.

LBNL Fiber System

- Stabilized fiber link:
  - Measure optical fringes in fiber
  - Shift phase of RF to compensate for measured changes in fiber length
- Specified at <100 femtosecond drift
  - Expect much better
- Different technology than DESY or NLC systems.

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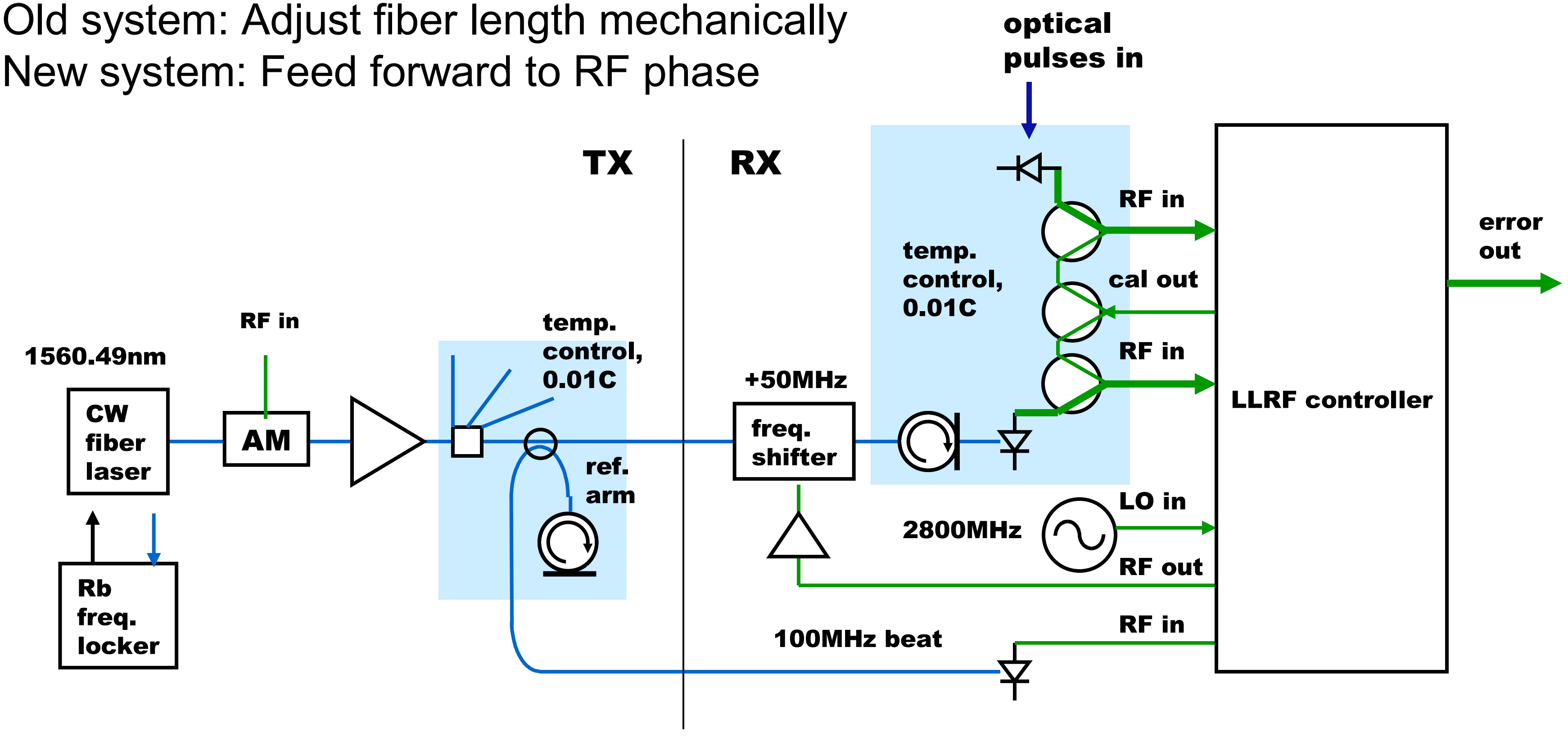
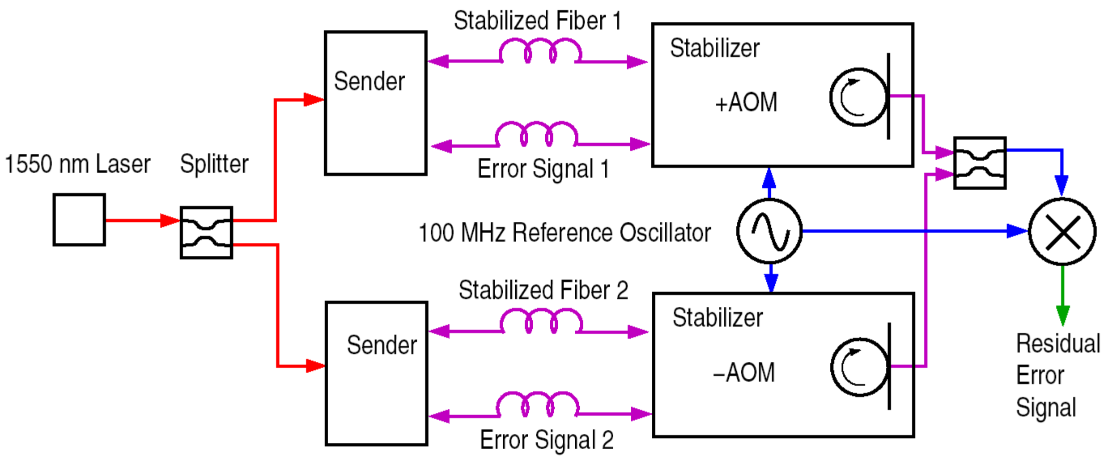
LBNL Fiber System

Measure fiber length interferometricaly
Old system: Adjust fiber length mechanically
New system: Feed forward to RF phase



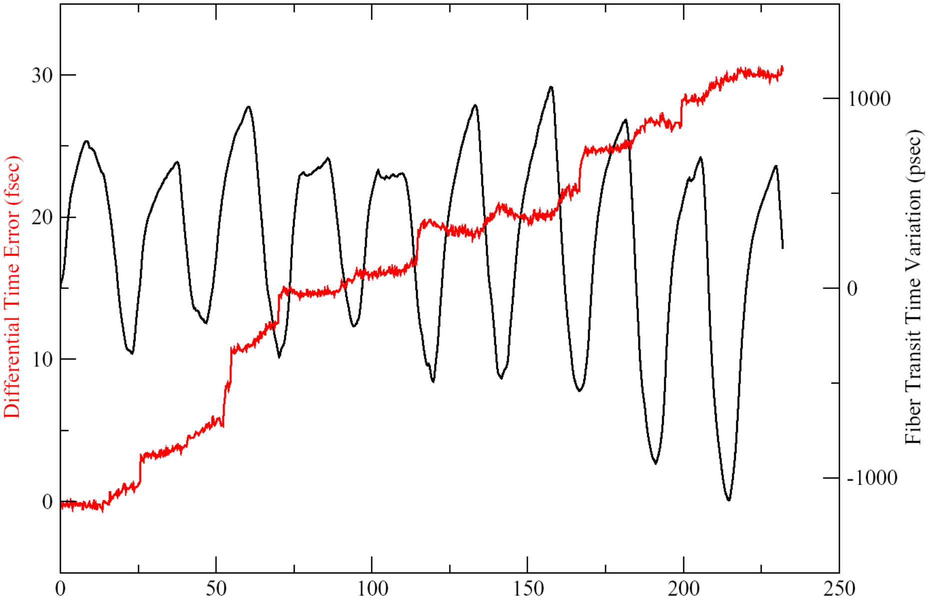
LBNL Test System

- 2, 2.8 Kilometer links in SLAC klystron Gallery
- Independently stabilize links, compare errors



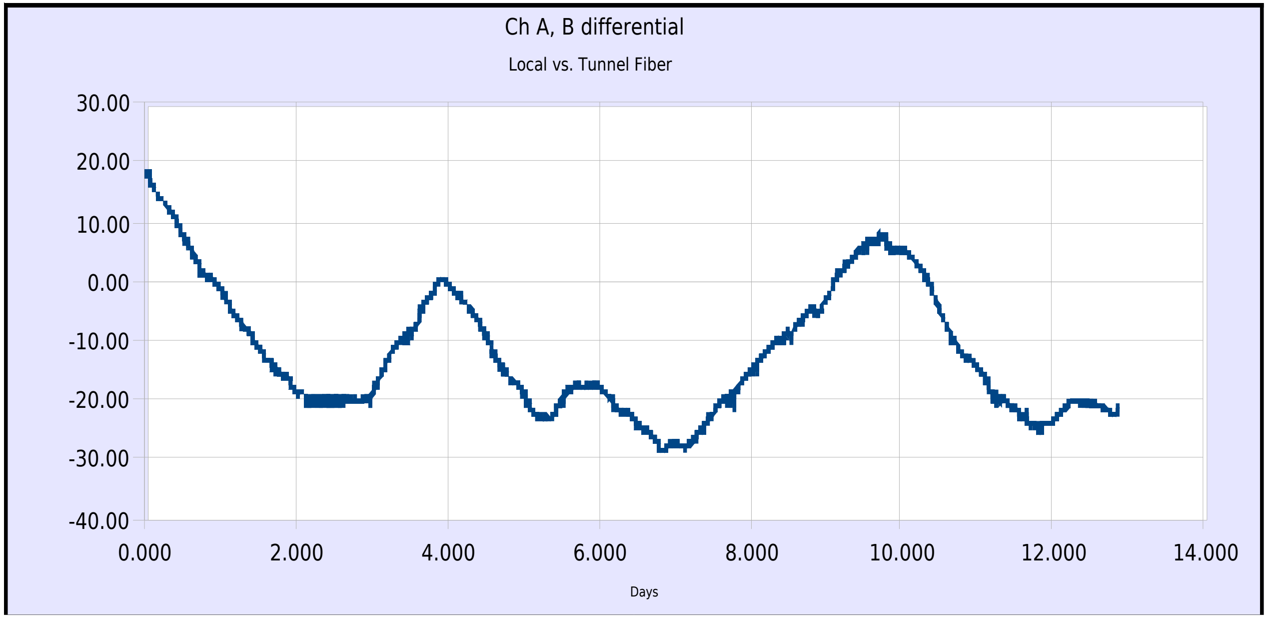
Test in SLAC Klystron Gallery

- 225 hour run
- Correcting fiber length change of ~ 1 nanosecond.
- Residual phase change ~20 fsec



Reference Arm Stability - Humidity

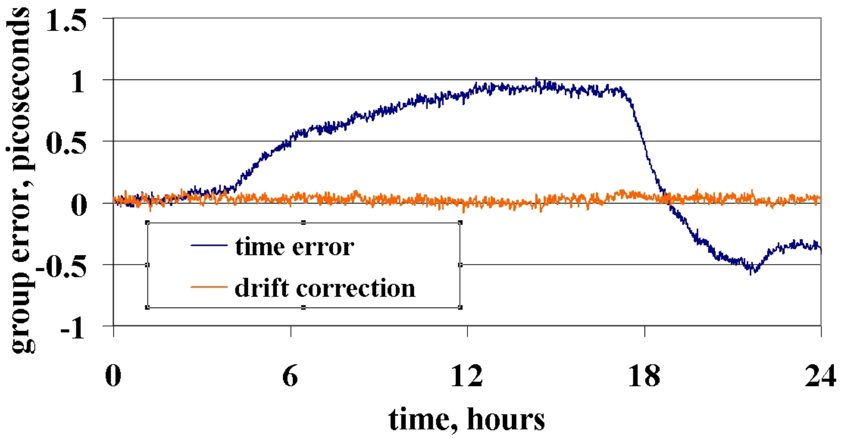
- Interferometer reference arm stability for temperature and humidity
  - 50 femtosecond variation



Delay variation in femtoseconds with humidity changes

Group Delay

- Interferometer fixes optical carrier, not RF modulated signal
- Fairly big effect: ~ 1 picosecond in test
- Size of effect known – fix in feedforward
- 36 femtosecond RMS achieved.



With and without group delay correction

AM to PM Conversion in Photodiode

- Need to connect “ugly” RF to “perfect” optical system.
- Photodiodes have phase delay dependent on optical power -> drift.
- Can select operating power so that there is no first order variation
- For 10% laser power variation, get 10 femtoseconds drift: OK

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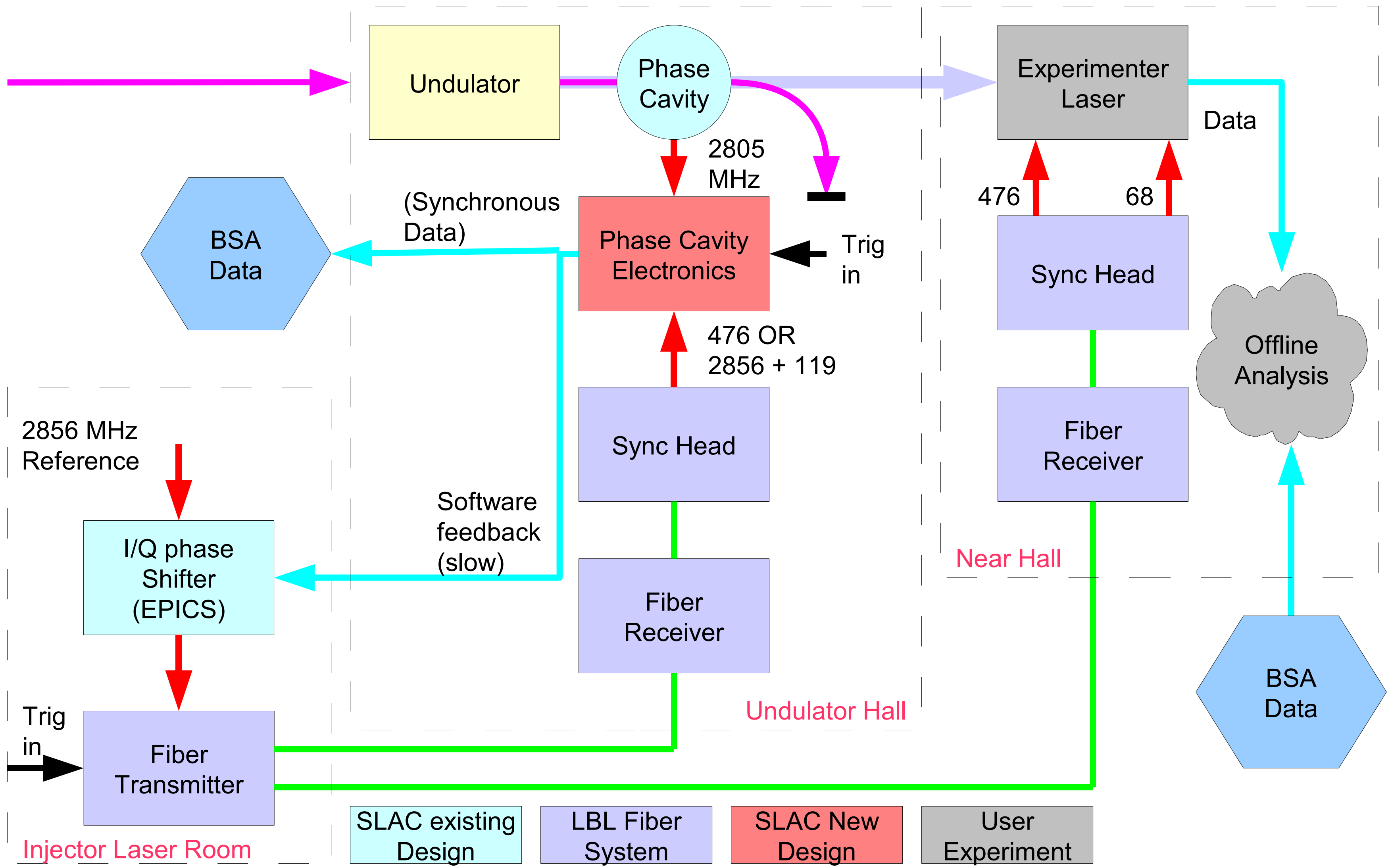
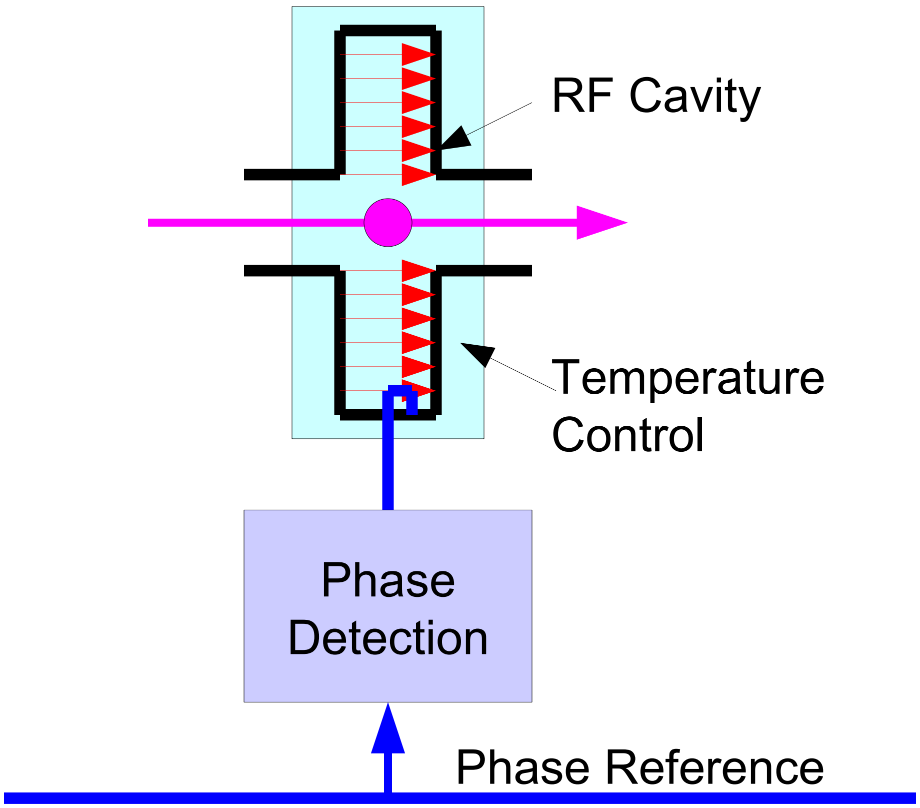

Undulator
Phase Cavity
2805 MHz
Experimenter Laser
Data
476
68
(Synchronous Data)
BSA Data
Phase Cavity Electronics
Trig in
Sync Head
476 OR 2856 + 119
Offline Analysis
2856 MHz Reference
Sync Head
Fiber Receiver
Software feedback (slow)
I/Q phase Shifter (EPICS)
Fiber Receiver
Near Hall
Undulator Hall
BSA Data
Trig in
Fiber Transmitter
Injector Laser Room
SLAC existing Design
LBL Fiber System
SLAC New Design
User Experiment

Phase Cavity



- Energy deposited by beam is large
  - Noise is insignificant
- High Q reduces peak power seen by electronics
  - Reduce non-linear amplitude → phase
  - Increases drift

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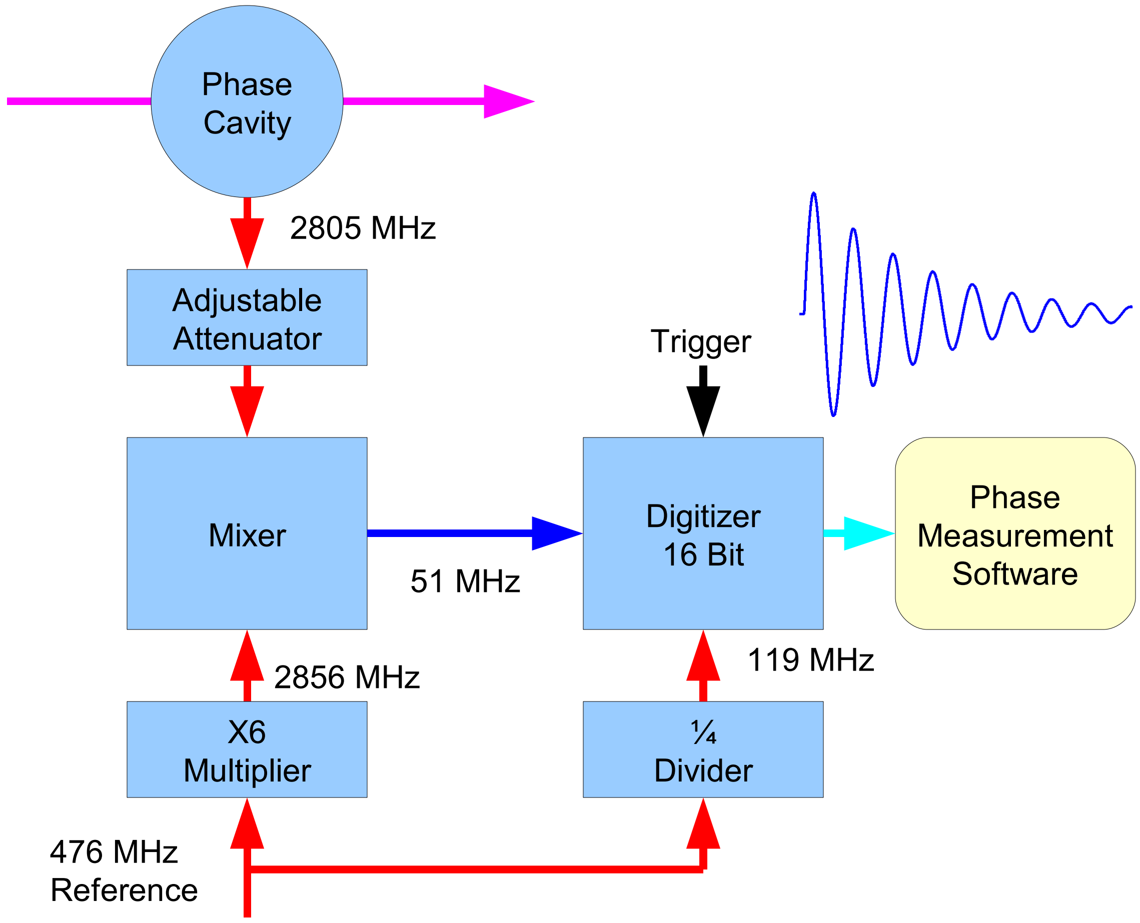
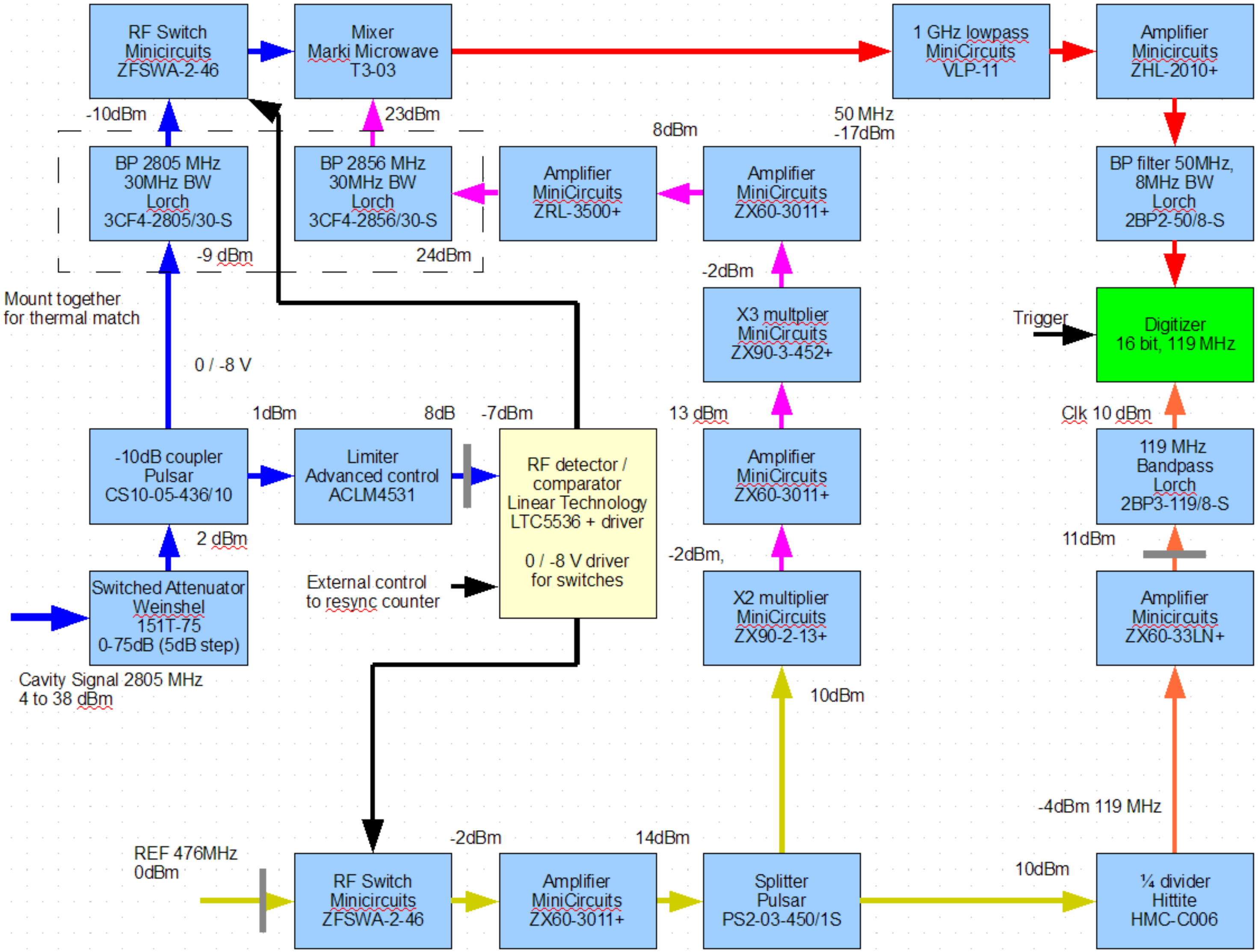
Block Diagram of Phase Cavity System





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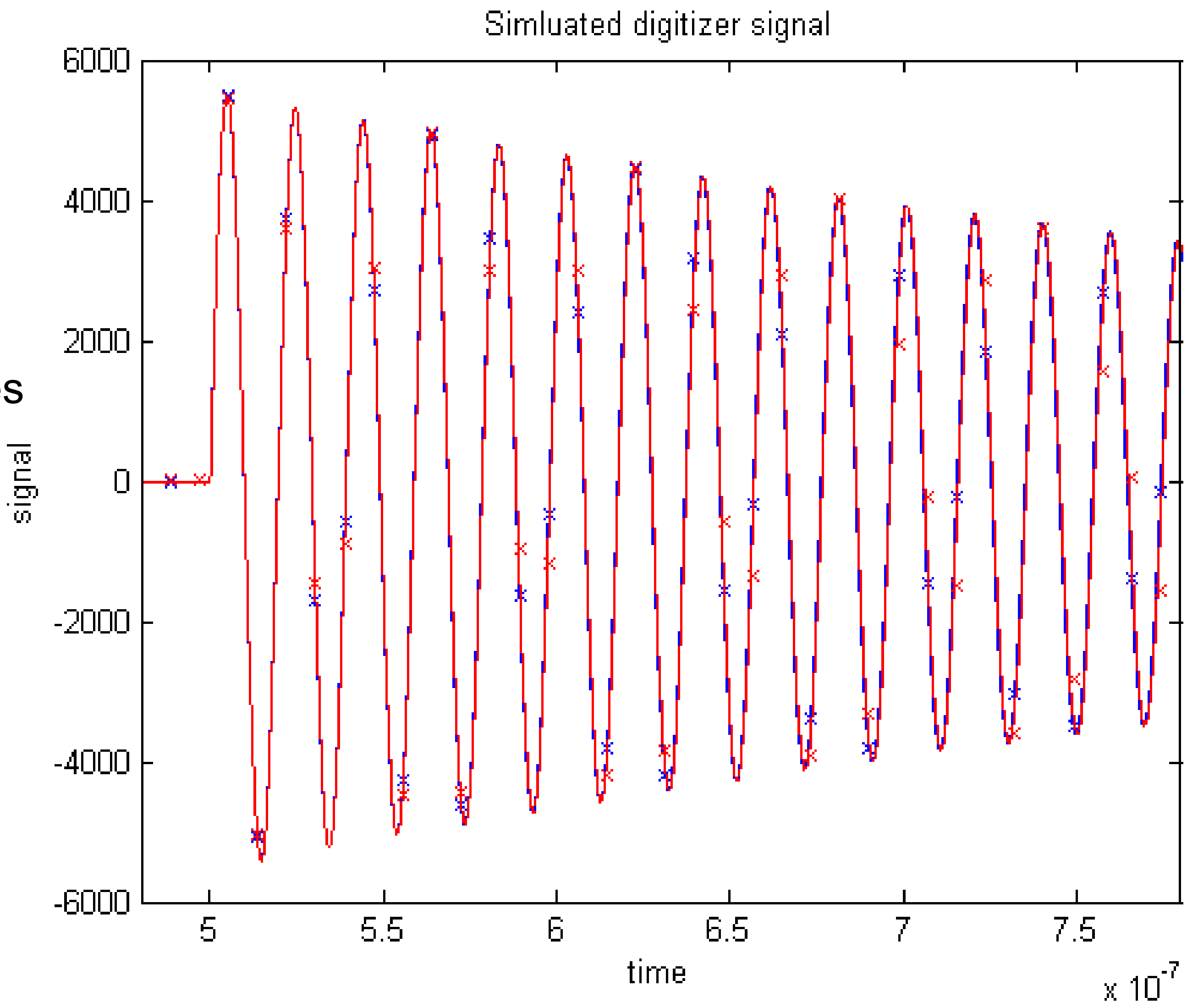
Phase Cavity Noise Sources

- **Electronic Noise**:
  - < 10 attoseconds thermal noise
  - Amplitude to phase conversion → Limit signal levels to maintain electronics linearity.
  - **Digitizer noise**: 16 bit (14 effective) 119MHz digitizer. Need to scale signal correctly
  - Result is < 1 femtosecond RMS.
- **Reference phase noise:**
  - Assume 476 MHz oscillator -150dBC/Hz from 10-200KHz. : 5 femtoseconds RMS

Phase Cavity Phase Drifts

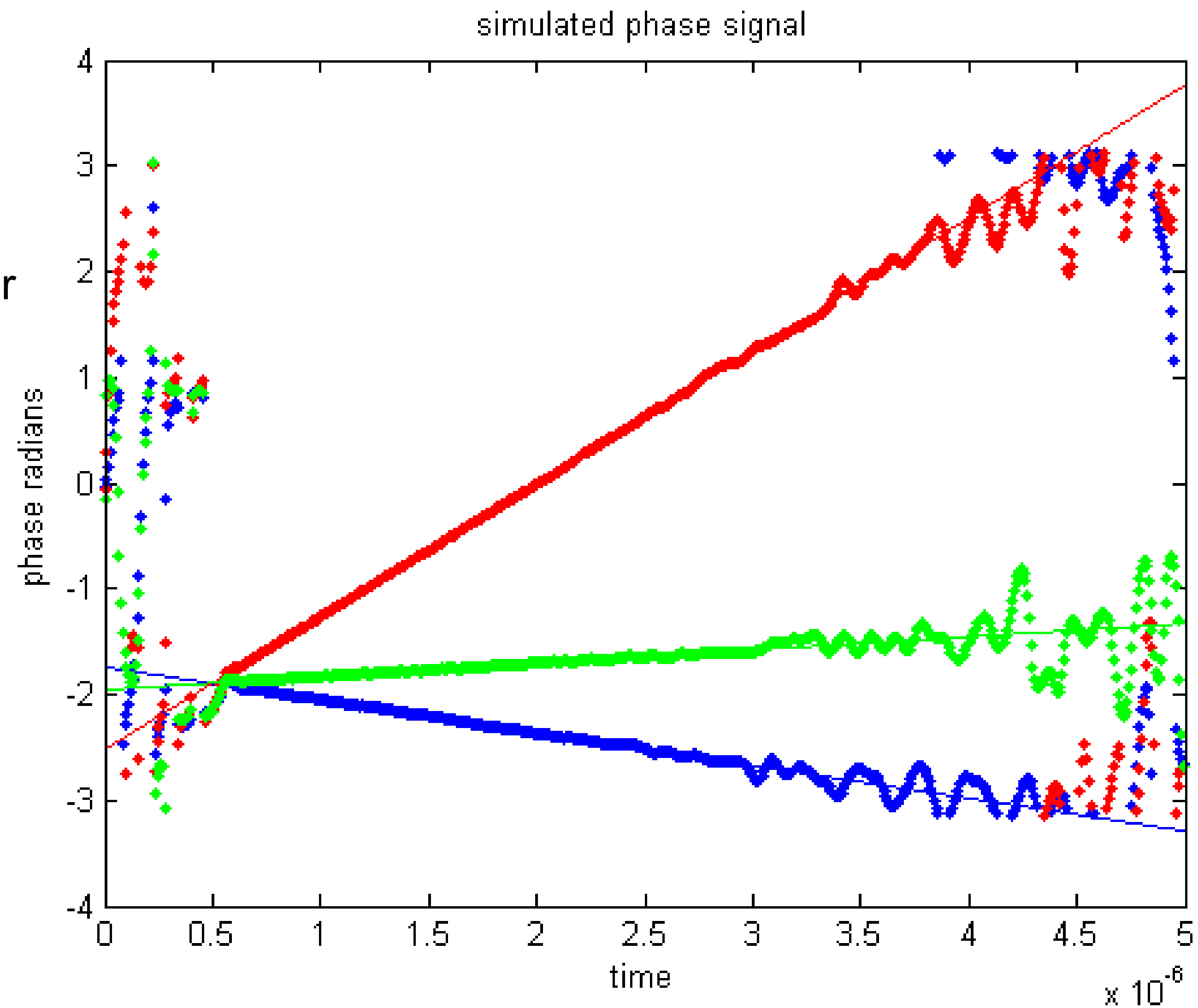
- Cavity frequency drifts 1.6×10^{-5}/C°.
  - 0.1 C° temperature change → 300 femtoseconds
  - Need temperature correction algorithm
- Cable drifts:
  - Use short (2M), temperature compensated cables
  - Estimate phase drift <2 fsec for 0.1 C°
- Electronics drift:
  - Filter delays compensated.
  - Component drifts not specified

Simulated IF waveforms and digitizer samples for 2 different cavity temperatures



Cavity phase for 3 different temperatures.

Note crossing point.



Existing Phase Cavities

- Use same 2805 MHz phase cavity design as new system.
- Use existing LLRF phase measurement hardware
  - Simple, but no programmable gain for bunch charge changes
- Performance still very good:

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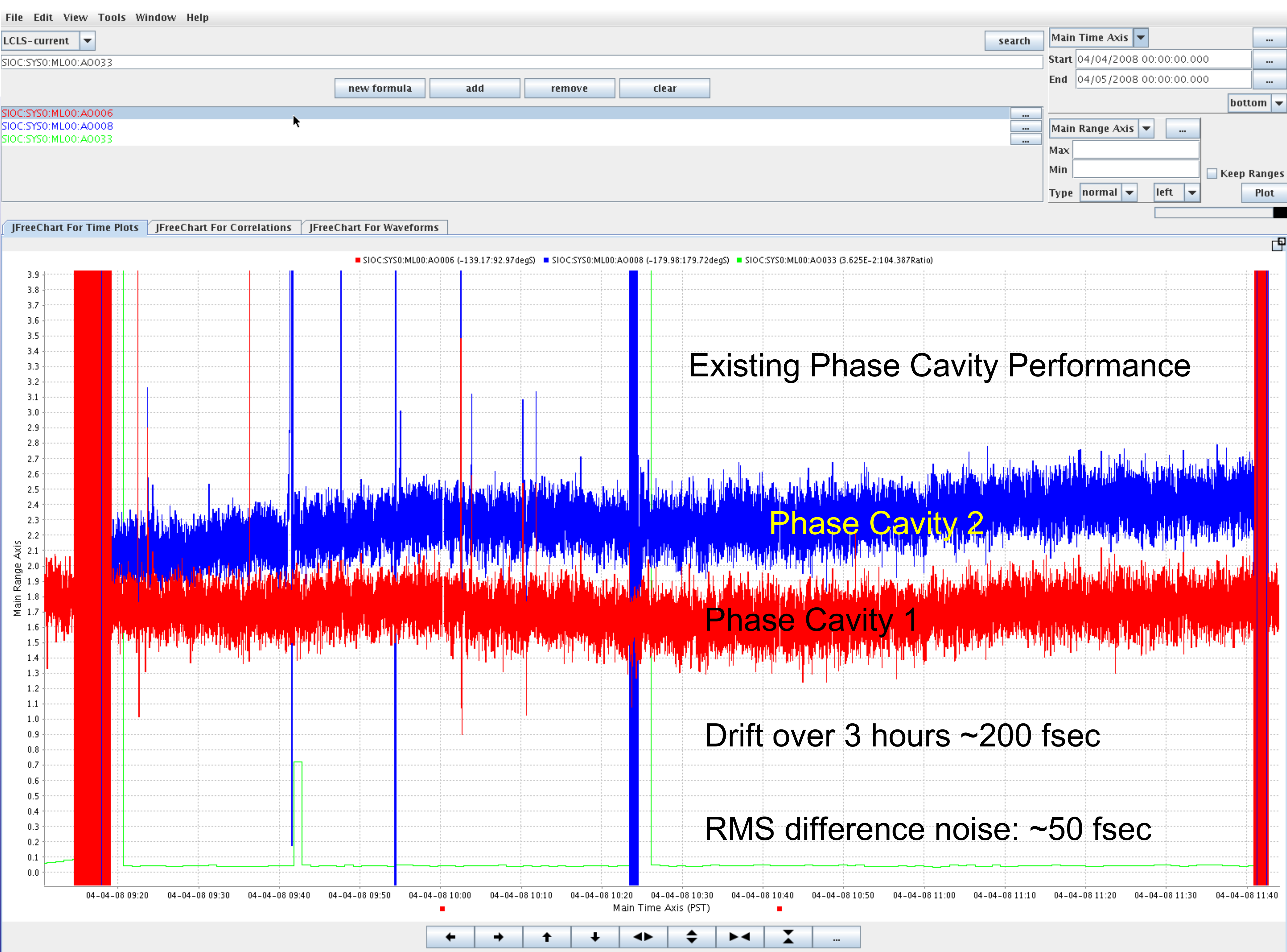
File Edit View Tools Window Help
LCLS-current
search
SIOC:SYS0:ML00:AO033
new formula
add
remove
clear
SIOC:SYS0:ML00:AO006
SIOC:SYS0:ML00:AO008
SIOC:SYS0:ML00:AO033
Main Time Axis
Start 04/04/2008 00:00:00.000
End 04/05/2008 00:00:00.000
bottom
Main Range Axis
Max
Min
Keep Ranges
Type normal left
Plot
JFreeChart For Time Plots
JFreeChart For Correlations
JFreeChart For Waveforms
SIOC:SYS0:ML00:AO006 (-139.17:92.97degS)
SIOC:SYS0:ML00:AO008 (-179.98:179.72degS)
SIOC:SYS0:ML00:AO033 (3.625E-2:104.387Ratio)
Main Range Axis
Main Time Axis (PST)
04-04-08 09:20
04-04-08 09:30
04-04-08 09:40
04-04-08 09:50
04-04-08 10:00
04-04-08 10:10
04-04-08 10:20
04-04-08 10:30
04-04-08 10:40
04-04-08 10:50
04-04-08 11:00
04-04-08 11:10
04-04-08 11:20
04-04-08 11:30
04-04-08 11:40
Existing Phase Cavity Performance
Phase Cavity 2
Phase Cavity 1
Drift over 3 hours ~200 fsec
RMS difference noise: ~50 fsec

Temperature Compensation Algorithm

- Measure phase vs. time on each pulse
- Linear fit back to beam time.
  - Phase at beam time is independent of cavity temperature.
- With 10 nanosecond accuracy, can measure phase to ~ 10 femtoseconds (for 0.1 C°)
- With 2 cavities, can change temperature to find effective arrival time to < 1nsec
  - Should give ~ femtosecond stability.

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Expected Phase Cavity Performance

- High confidence noise and drift < 100 femtoseconds.
- Calculated short term noise 5 femtoseconds RMS.
- Known drift sources ~ 5 femtoseconds
  - Don't really believe this!!
- Build initial system and see what limits performance.

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Status

- BNL Fiber system
  - Expect installation before first user experiments
  - Can use non-stabilized system as fall-back
- Phase Cavity
  - Expect hardware ready by March.
  - Slow software ready by user experiments
    - LCLS RMS jitter ~50 fsec RMS
  - Pulse-to-pulse synchronous software later
- Still thinking about X-ray timing

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