Timing and Synchronization for SPX

Frank Lenkszus

SPX Studies Mini-Workshop
July 18-20, 2011

Outline

- Background
- Design Goals and Performance Requirements
- Technical Challenges
- Conceptual Design Approach
- R&D approach
- Summary

Team

- Timing/Synchronization
  - Frank Lenkszus - Lead Engineer
  - Tony Scaminaci - FPGA Engineer
- LLRF
  - Tim Berenc - Lead Engineer
  - Hengjie Ma – LLRF Engineer
- Controls
  - Ned Arnold
- LBNL Collaborators
  - John Byrd
  - Larry Doolittle
  - Gang Huang

Background

- SPX Technical Study Meeting July 2010
  - WG2: LLRF/Timing/Synchronization/Diagnostics/Controls
- Timing/Synchronization WG Meeting Dec 2010
- Meeting with John Byrd of LBNL Jan 2011
- SPX Review March 2011
- Lehman Review May 2011
- Weekly Skype meetings with LBNL group
  - John Byrd
  - Larry Doolittle
  - Gang Haung
  - Tim Berenc
  - Frank Lenkszus
  - Ned Arnold
  - Hengjie Ma

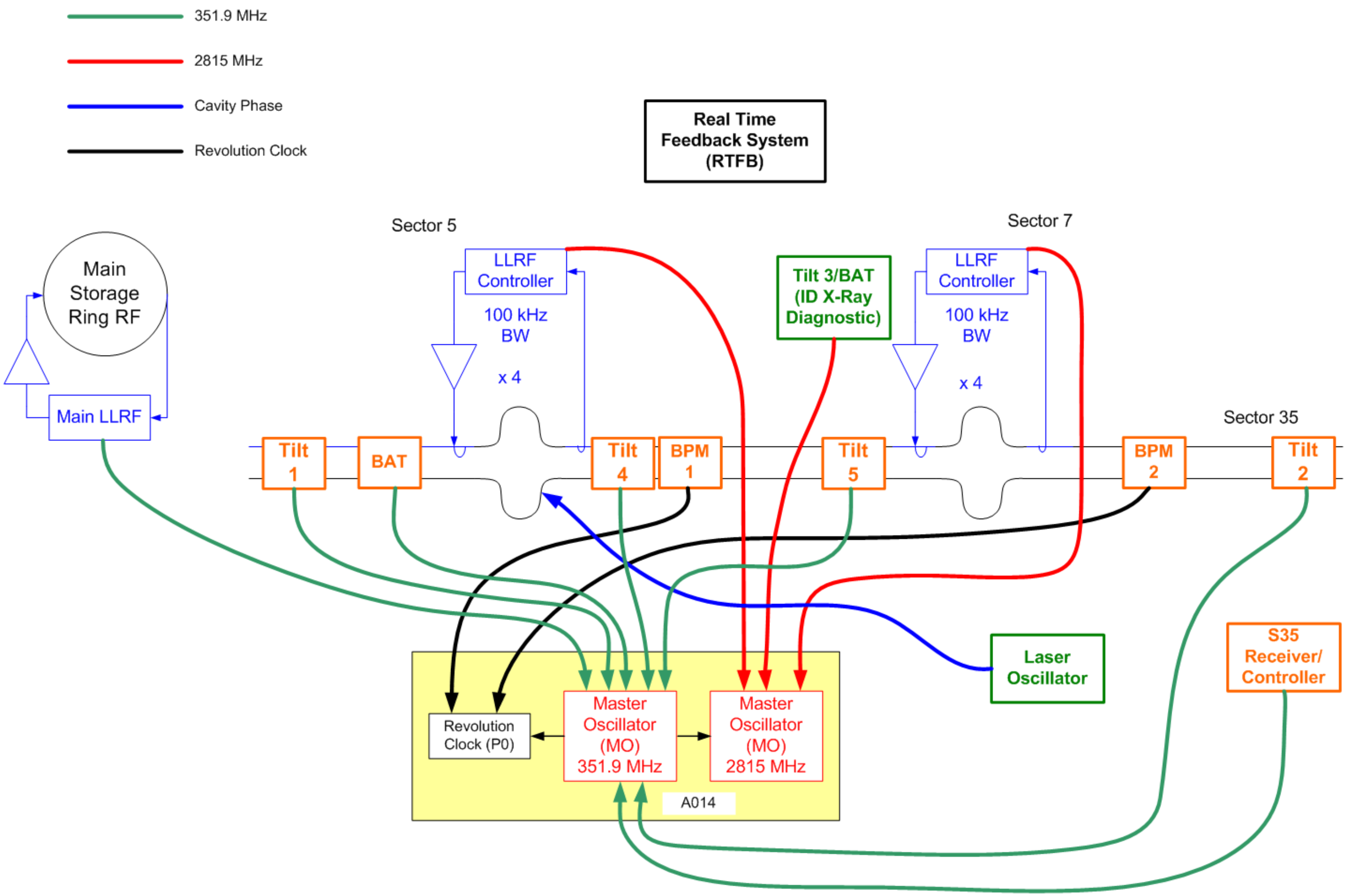
Cavity Field Specifications

Specification name	Rms Value	Driving requirement
Common-mode voltage variation	< 1%	Keep intensity and pulse length variation under 1% rms
Common-mode phase variation	$< 4.0^{o}$	Keep intensity variation under 1% rms
Voltage mismatch between cavities	< 1.1%	Keep rms emittance variation under 10% of nominal 40 pm
Phase error between cavities	$< 0.18^{o}$	Keep rms beam motion under 10% of beam size/divergence

Timing/Synchronization Requirements per Device

		F in MHz	Reference With respect to What	Stability (rms) (< 10 Hz)	Interval	Phase Noise (>10 Hz)	System Response BW	P0 (rev clock)	Note
Beam Arrival Time Monitor	Ref	2815	352 Mo	< 1 ps	7 Days?	TBD	3kHz	Yes	Short Copper <10m
RF Beam Tilt Monitor (Residual)	Ref	11260	352 Mo	< 1ps	7 Days	TBD	3kHz	Yes	Short Copper <10m
RF Beam Tilt Monitor (Residual)	ADC Clock	TBD		TBD	TBD	TBD	TBD		
X-Ray Tilt Monitor	Ref	2815	2815 Ref	2 ps	7 Days	TBD	1Hz		ID & BM Relative measurement between array elements
X-Ray BAT	Ref	2815	2815 Ref	250fs	7 Days	TBD	1Hz		ID & BM (BAT monitor uses same sensor as tilt monitor)
Laser(s)	Ref	Various	2815 US cavity zero crossing + x-ray arrival time	<100 fsec	7 Days?	TBD	1Hz	Yes	
Laser(s)	Rev Clk	272 kHz							
S35	Ref	2815	352 Mo	<4.8 psec	7 Days?	TBD	0.1Hz		
RF BPMs	Rev Clk	272 kHz						Yes	

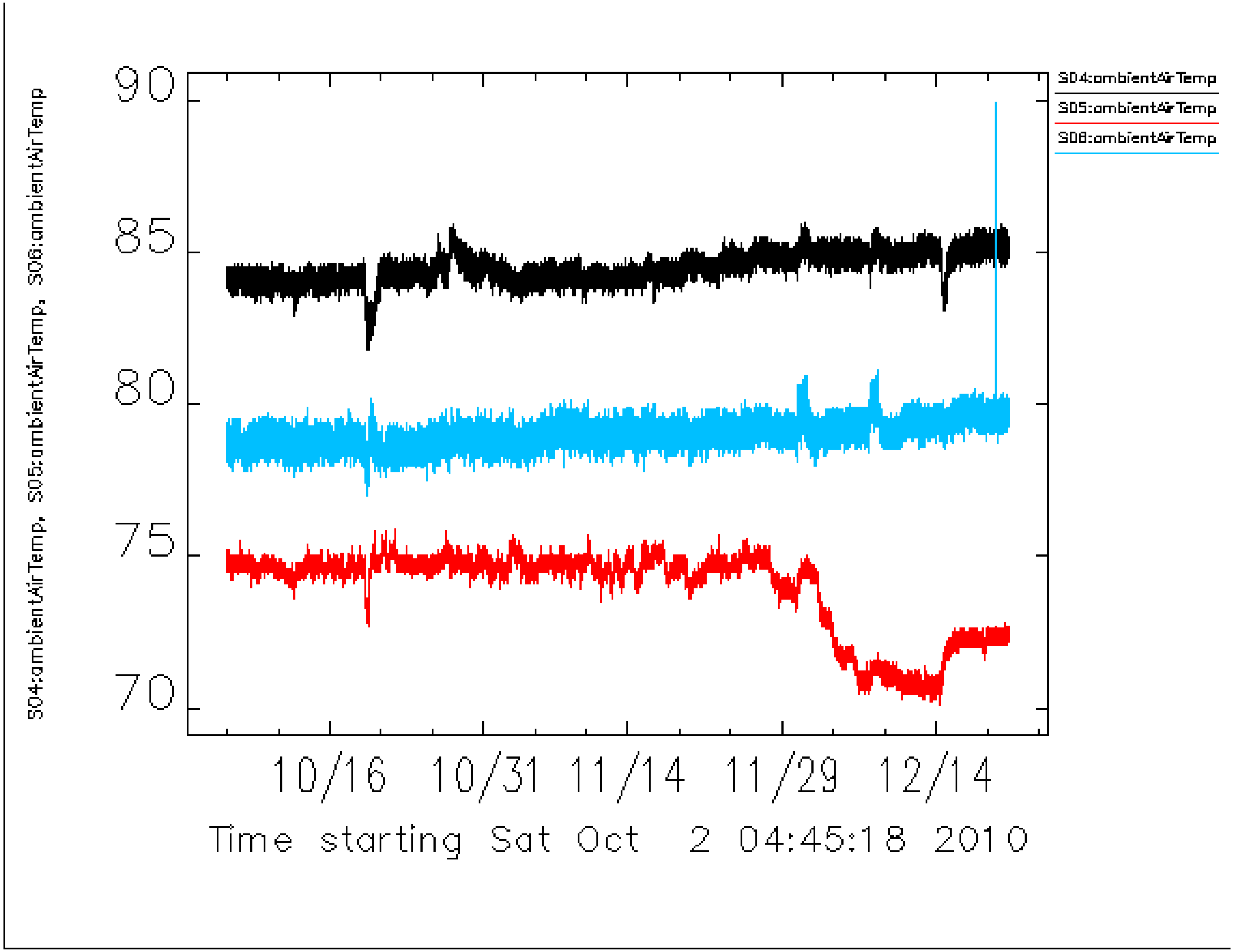
Device Phase Reference Sources



BPM 1 – Sets Phase of Sect 5 RF
Tilt 3 – Calibrates Amplitude of Sect 5

BPM 2 – Sets Phase of Sect 7
Tilt1 & Tilt2 Calibrate Amplitude of Sect 7

Ambient Temperature: SR S4, S5, S6



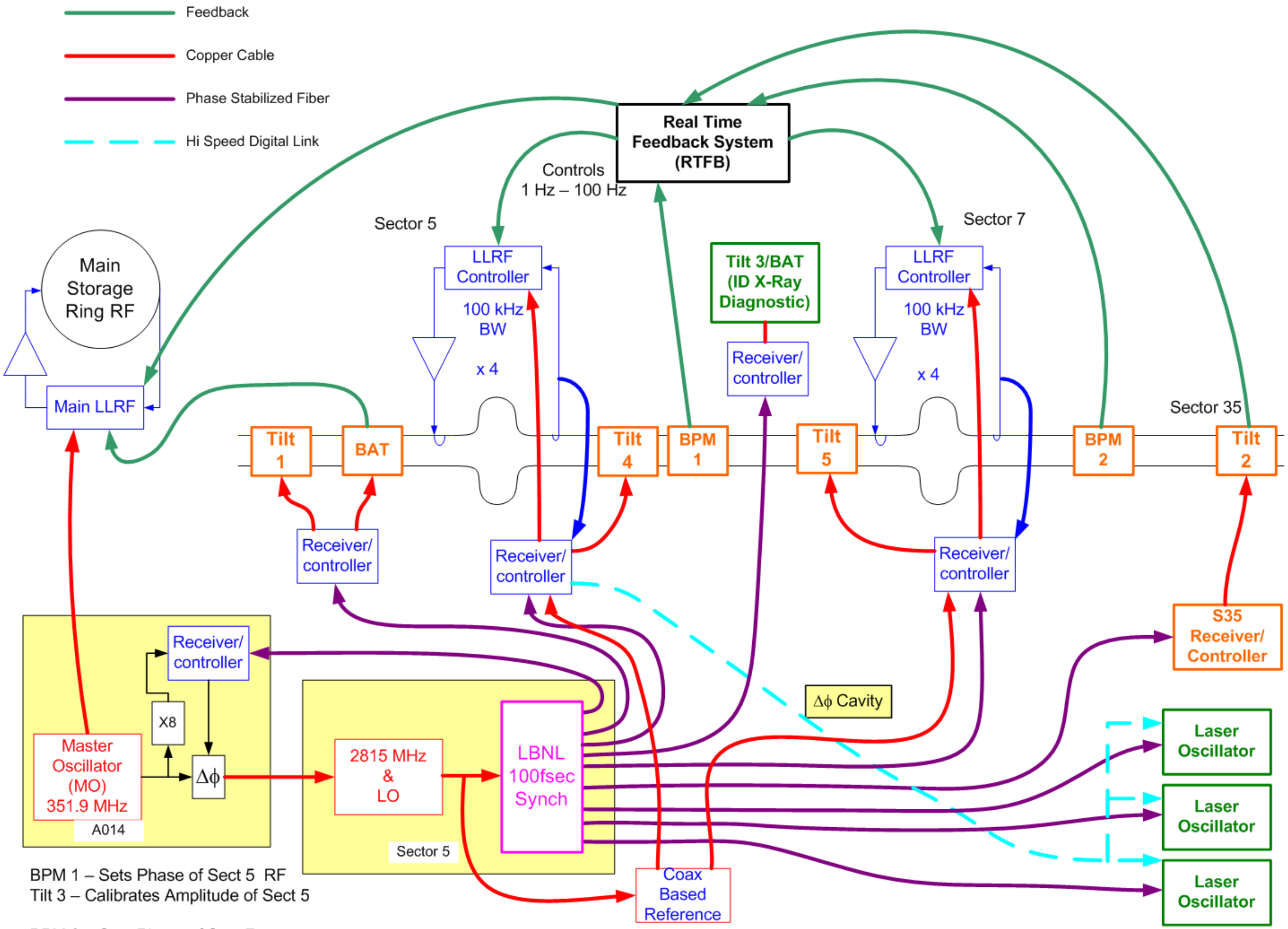
The Problem

- One Meter of Fiber Optic cable with
  - 7 ppm/degC
  - V/C = 67%
- Result: ***~50 femtoseconds/degC***
- 5 Meters of Phase Stabilized Coax Cable
  - 3 ppm/degC
  - V/C = 90%
- Result: ***~56 femtoseconds/degC***

Conceptual Design Approach

- Use the LBNL developed Femtosecond –Phase Stabilization Scheme to lock the beam-line pump laser(s) to the upstream SPX deflecting cavity phase.
- Use beam based feedback to compensate for “slow” drifts (<100 Hz)
  - BPMs within SPX zone correct upstream SPX cavity phase
  - BPMs outside SPX zone correct downstream SPX cavity phase
- Distribute common phase reference to up and down stream sector LLRF to keep phase noise common mode
  - Provide for both coax and LBNL stabilized fiber phase references
    - *Coax provides better short-term noise*
    - *Stabilized fiber provides better long term noise (stability)*
      - Reduces control effort required of beam-based feedback

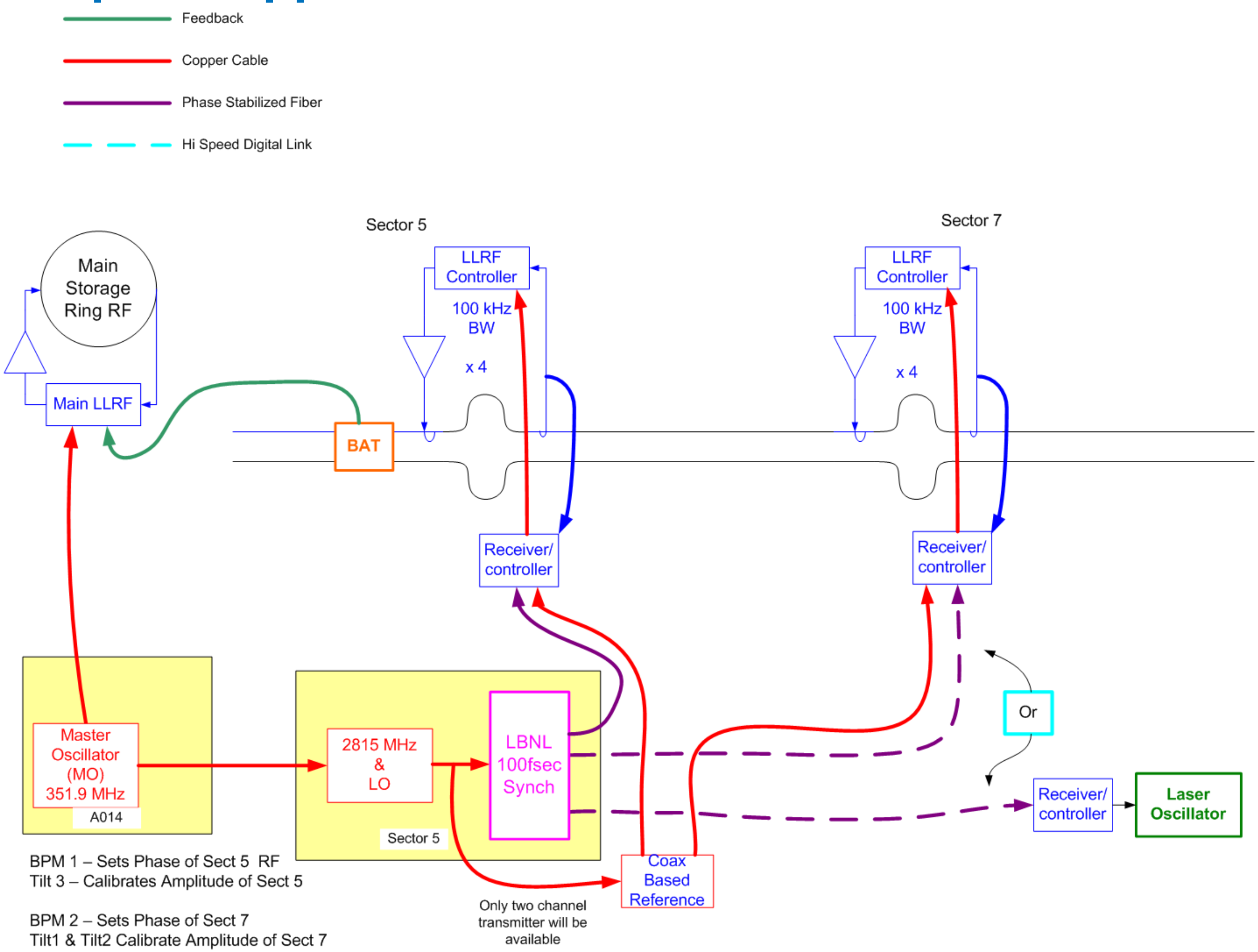
Conceptual Approach Production



BPM 1 – Sets Phase of Sect 5 RF
Tilt 3 – Calibrates Amplitude of Sect 5

BPM 2 – Sets Phase of Sect 7
Tilt1 & Tilt2 Calibrate Amplitude of Sect 7

Conceptual Approach R&D



BPM 1 – Sets Phase of Sect 5 RF
Tilt 3 – Calibrates Amplitude of Sect 5

BPM 2 – Sets Phase of Sect 7
Tilt1 & Tilt2 Calibrate Amplitude of Sect 7

Summary

- Timing/synchronization requirements determined for cavity field and beam diagnostics
- LBNL femtosecond phase reference distribution
  - Collaboration with LBNL
  - Two channel system for in-ring testing
    - *Borrowed LBNL transmitter*
- Beam based feedback to compensate for long term drifts

Additional Slides

Beam-Line Lasers

- High-peak-power Ti:Sapphire
  - Pulse Duration: 50 fs
  - Repetition rate: 1 – 10 kHz
- High Power, sub-cycle THz source
  - Pulse Duration: < 1 ps
  - Repetition rate: 1- 10 kHz
- Tuneable UV to mid-IR Source
  - Pulse Duration: < 100 fs
  - Repetition Rate: 1 – 10 kHz
- High Repetition-Rate, High Average Power fiber laser system
  - Pulse Duration: < 200 fs
  - Repetition Rate: 6.5 MHz

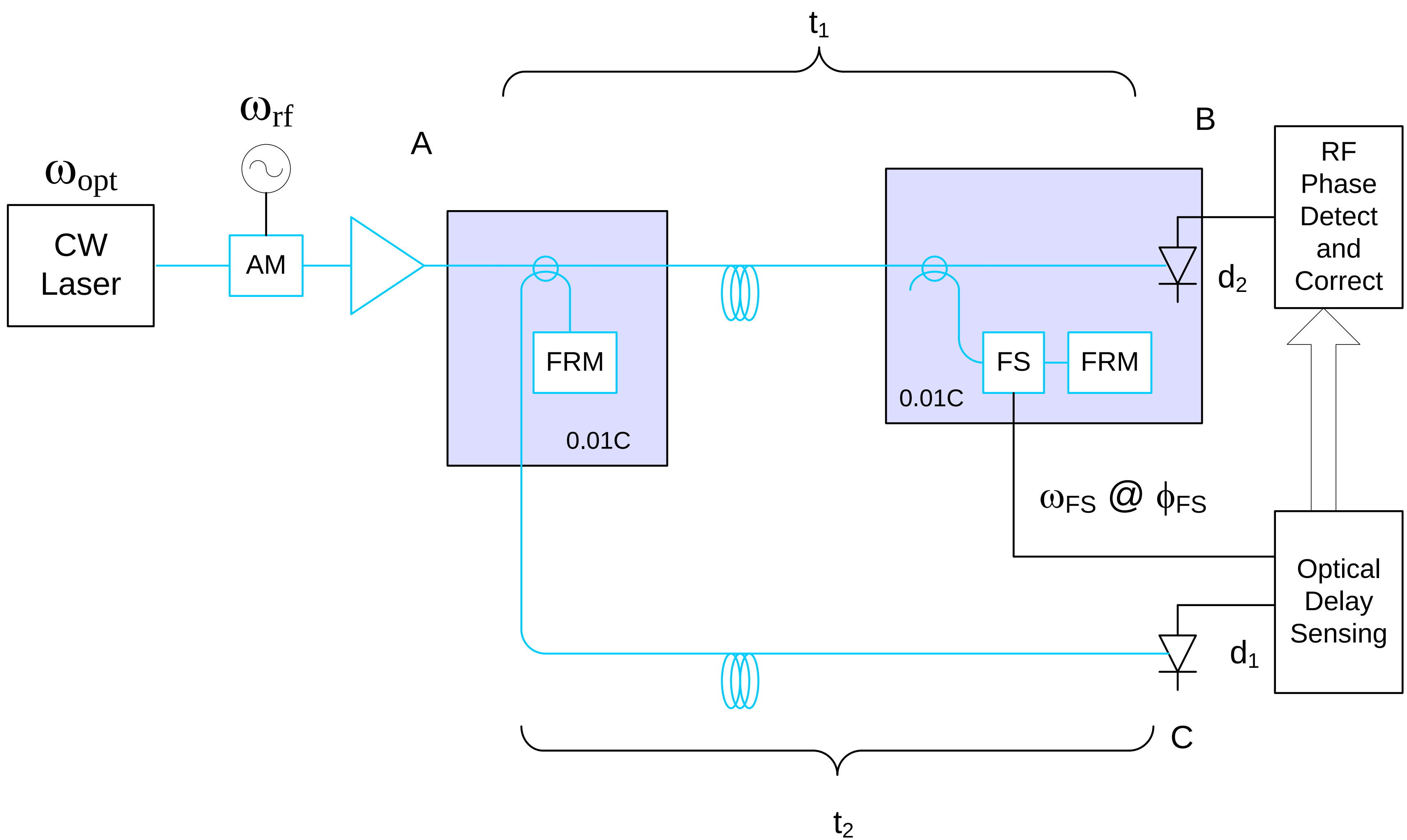
Ref: CDR 4.2.2.6

The LBNL Femtosecond-Phase Stabilization System

- Uses frequency offset in the optical domain
  - Optical frequency is offset by an RF frequency (110 MHz)
  - Offers a large leverage over stabilization in the RF domain (six-order-of-magnitude)
- The frequency offset process is equivalent to a heterodyning process
  - Heterodyne (mix) original optical frequency with the offset optical frequency
  - Changes in optical phase translate to identical changes in the 110 MHz beat signal
  - One degree of phase change in the 1530 nm optical domain translates to 1 degree of phase change in the RF domain. ~ 21 attoseconds

“Demonstration of Femtosecond-Phase Stabilization in 2 km Optical Fiber”, J. Staples, R. Wilcox, J. Byrd, LBNL, Proceedings of PAC07 (MOPAS028)

LBNL Scheme for stable transmission of RF signals



Reference: "Stable transmission of radio frequency signals on fiber links using interferometric delay sensing", R. Wilcox, J. Byrd, L. Doolittle, G Huang, J. Staples, Optics Letters, Vol 34, No. 20, pp 3050-3052 (Oct 15, 2009)

LBNL Results

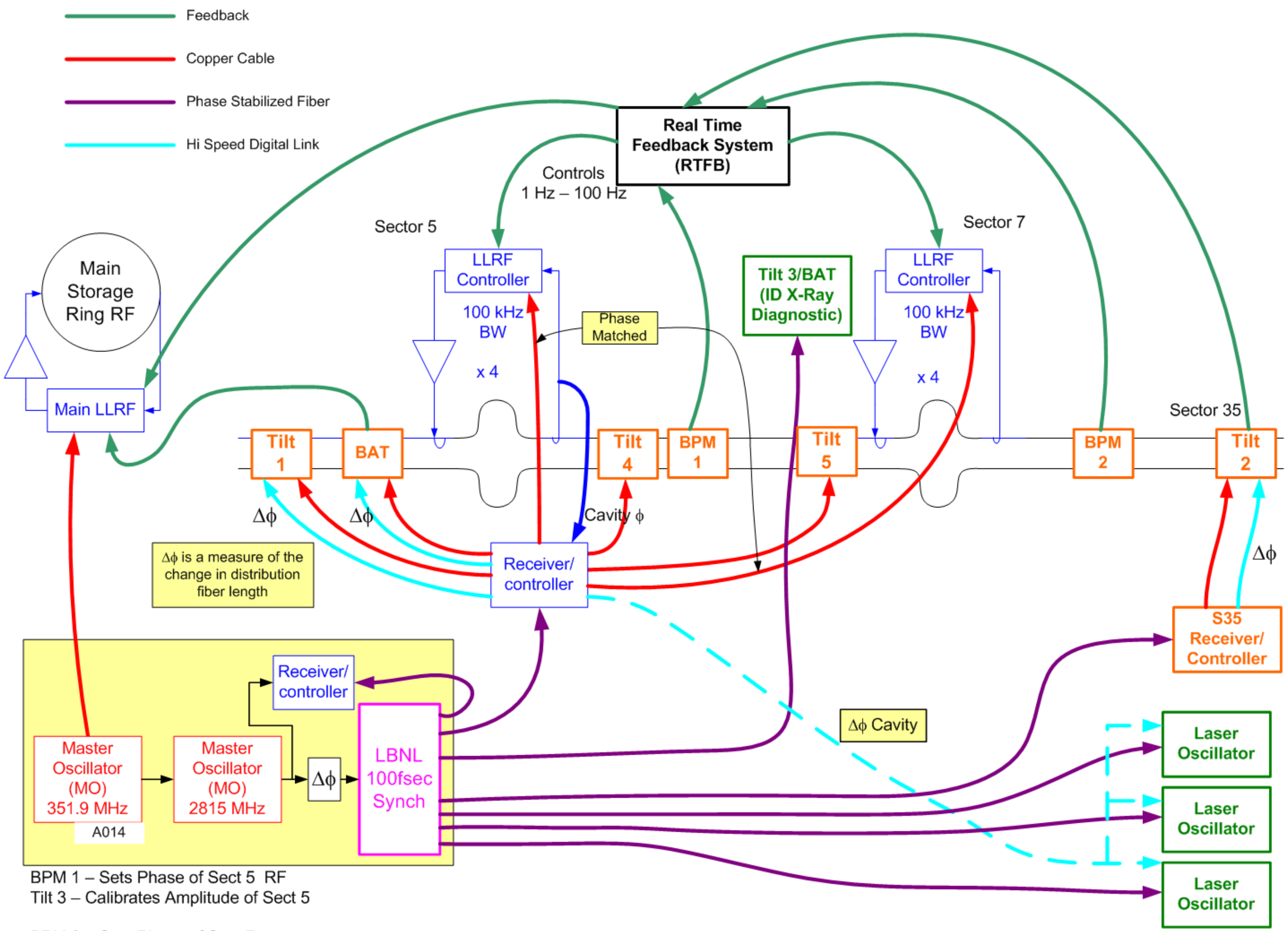
- 2.2 km fiber
  – 19.4 fs rms @ 2850 MHz (60 hours)
- 200 m fiber
  – 8.4 fs rms @ 2850 MHz (20 hours)

Reference: "Stable transmission of radio frequency signals on fiber links using interferometric delay sensing", R. Wilcox, J. Byrd, L. Doolittle, G Huang, J. Staples, Optics Letters, Vol 34, No. 20, pp 3050-3052 (Oct 15, 2009)

Notes on the LBNL System

- CW laser used in the interferometer must have a fractional frequency stability less than the desired fractional temporal stability.
  - For 10 femtosecond stability
    - *2 km link – $\Delta\lambda/\lambda = 1 \times 10^{-9}$*
    - *500 m link – $\Delta\lambda/\lambda = 4 \times 10^{-9}$*
  - CW laser frequency is locked to a hyperfine absorption line in Rb vapor
    - *May be able to use an acetylene line – lower cost*
- Method stabilizes the phase velocity of the optical frequency
  - Apply a fixed correction factor to correct group velocity.
- AM/PM conversion in photo diode must be minimized
  - Operate photo diode at power level to minimize AM/PM conversion if possible
- Critical rf and optical components are temperature stabilized to +/- 0.01 ^{o}C
- RF mixers and amplifiers are stabilized to +/- 0.1 ^{o}C
- No optical delay line needed
- Links need to be recalibrated after a power cycle.

SPX Timing/Synchronization Distribution



BPM 1 – Sets Phase of Sect 5 RF
Tilt 3 – Calibrates Amplitude of Sect 5

BPM 2 – Sets Phase of Sect 7
Tilt1 & Tilt2 Calibrate Amplitude of Sect 7

Notes

- Fiber Transmitter/Modulator stabilized by feedback
  - Use one fiber splitter output for feedback to control phase shifter on transmitter modulator input
- SPX Upstream cavity phase measured and distributed digitally to Laser receiver controllers to correct for cavity phase shifts