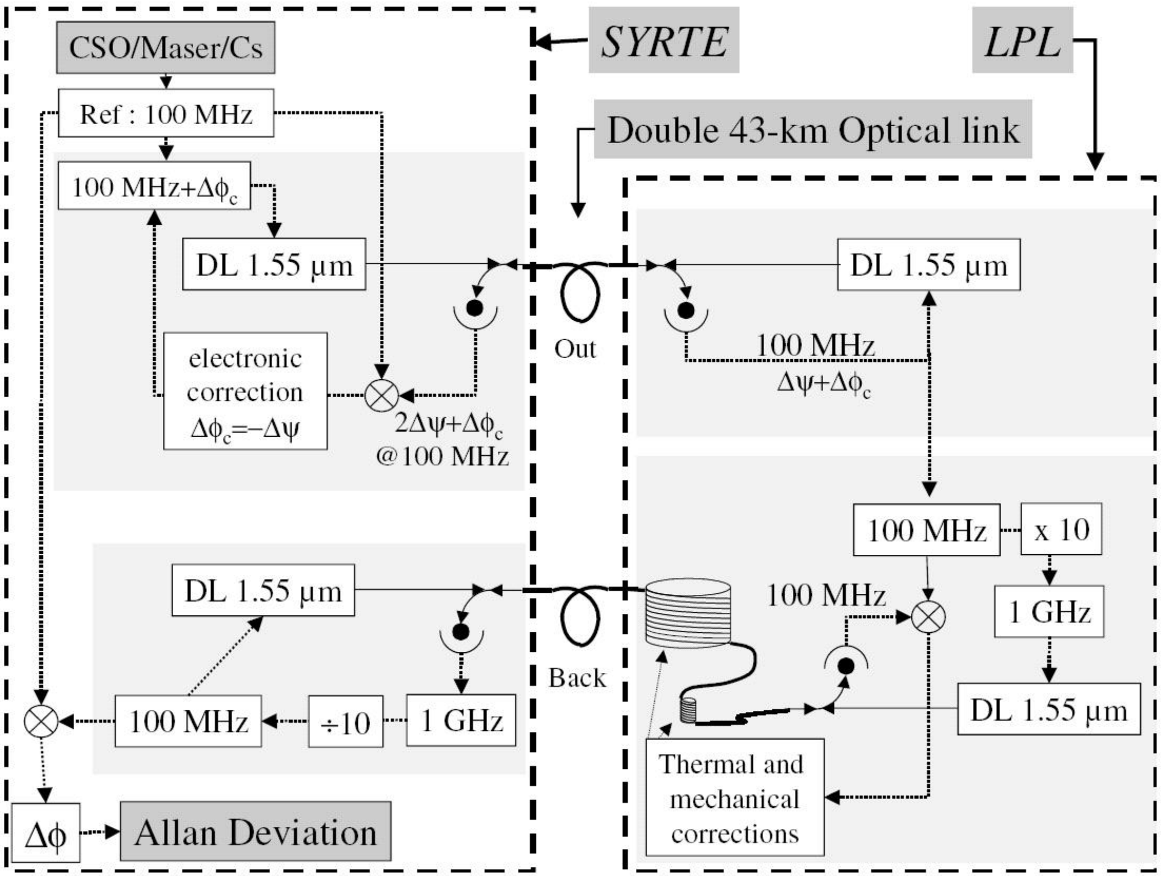
Part 7: Demonstrated frequency transmission schemes

Examples of demonstrated systems

- Modulated CW + interferometer
- Modulated CW + envelope detection
- Two CW frequencies
- One freq. + interferometer
- Short pulses + cross correlation
- Short pulses + phase detector
- Two CW frequencies + interferometer + mixing
- Phase shifting transmitted RF

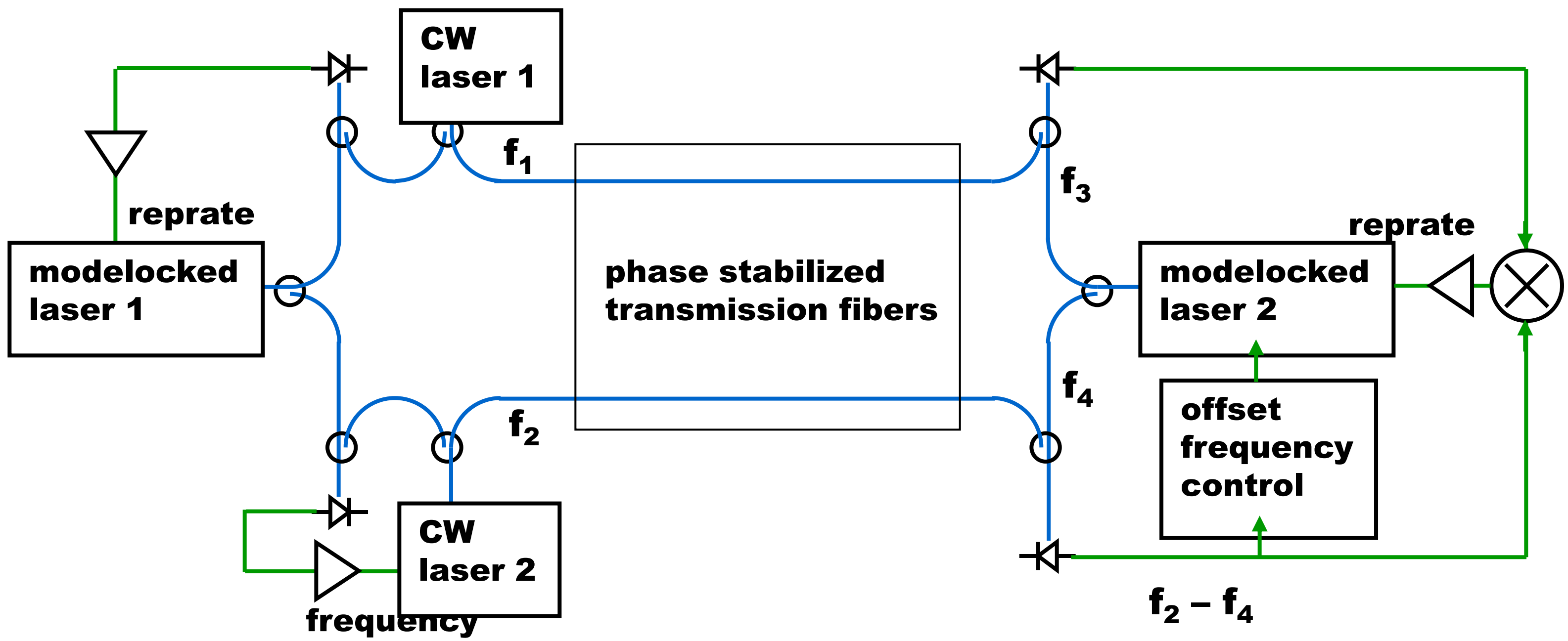
Modulated CW + envelope detection



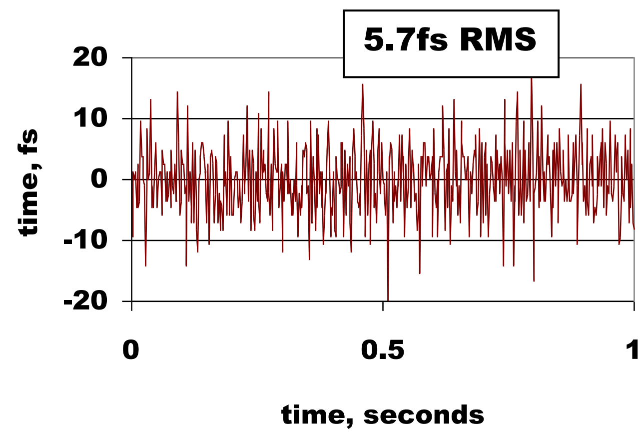
- **Daussy et al at LPL, SYRTE, UWA**
  - **86km fiber, 3x10-14 at 1 sec (~17fs averaged over 1s)**
  - **Directly modulated diode lasers, AM detected by photodiodes**
  - **Metro fiber around Paris**

PRL 94, 203904 (2005)

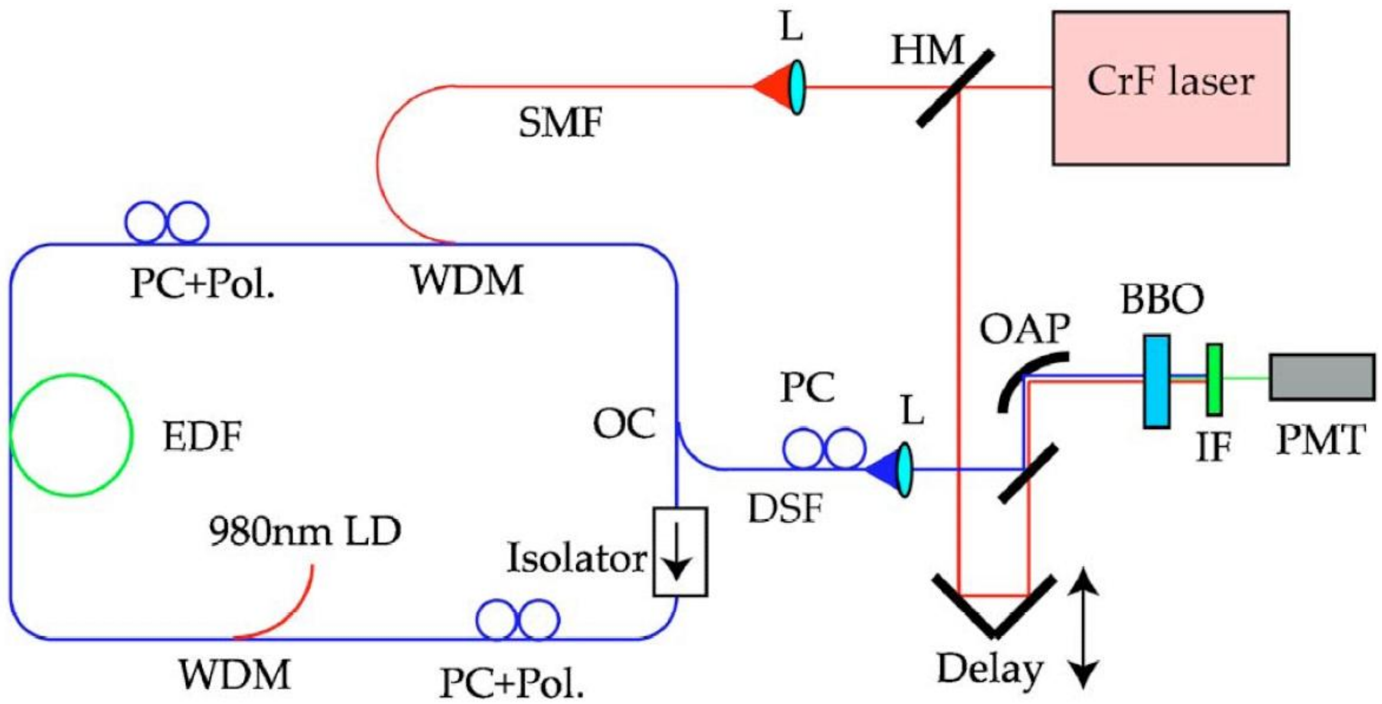
Two CW frequencies (LBL2)



- Wilcox and Staples at LBNL
  - Adjacent lasers, 5.7fs from 1Hz to 100kHz
  - Interference of 0.8nm wide groups of comb lines 40nm apart
- CW frequencies can be transmitted via phase-stabilized fiber



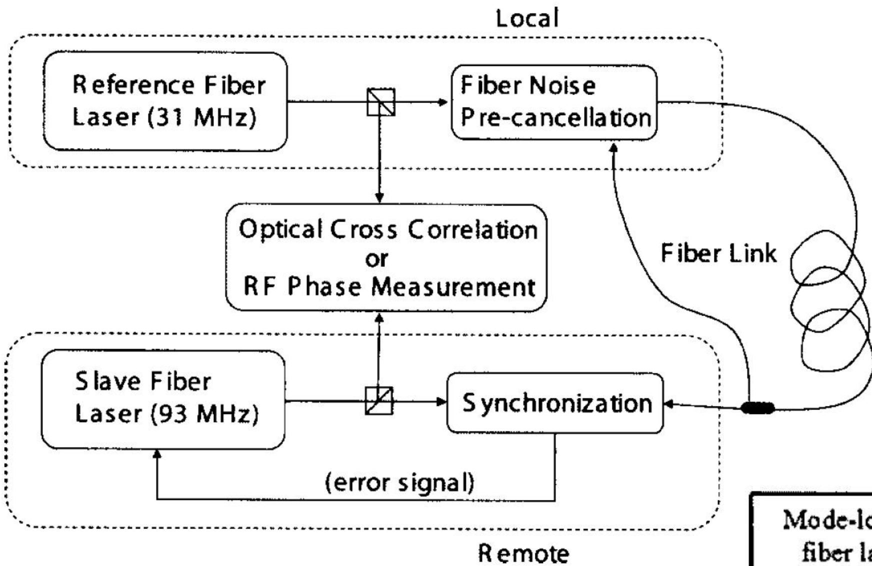
Synching with cross-phase modulation



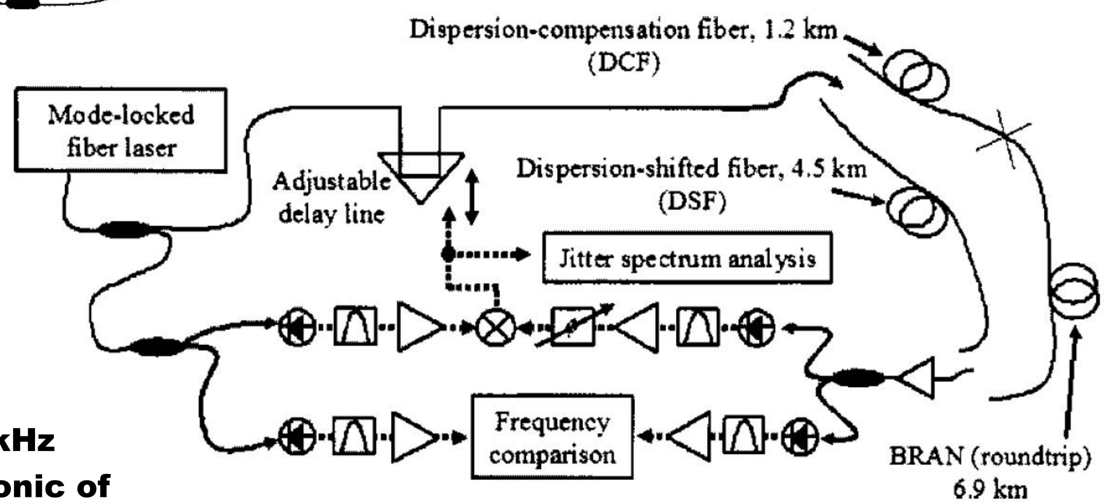
Opt. Lett. 31, 3243 (2006)

- Yoshitomi et al at AIST
  - Adjacent lasers, 3.7fs from 1Hz to 100kHz
  - One laser phase modulates the other via nonlinear optics in fiber

Detection of pulse train as RF



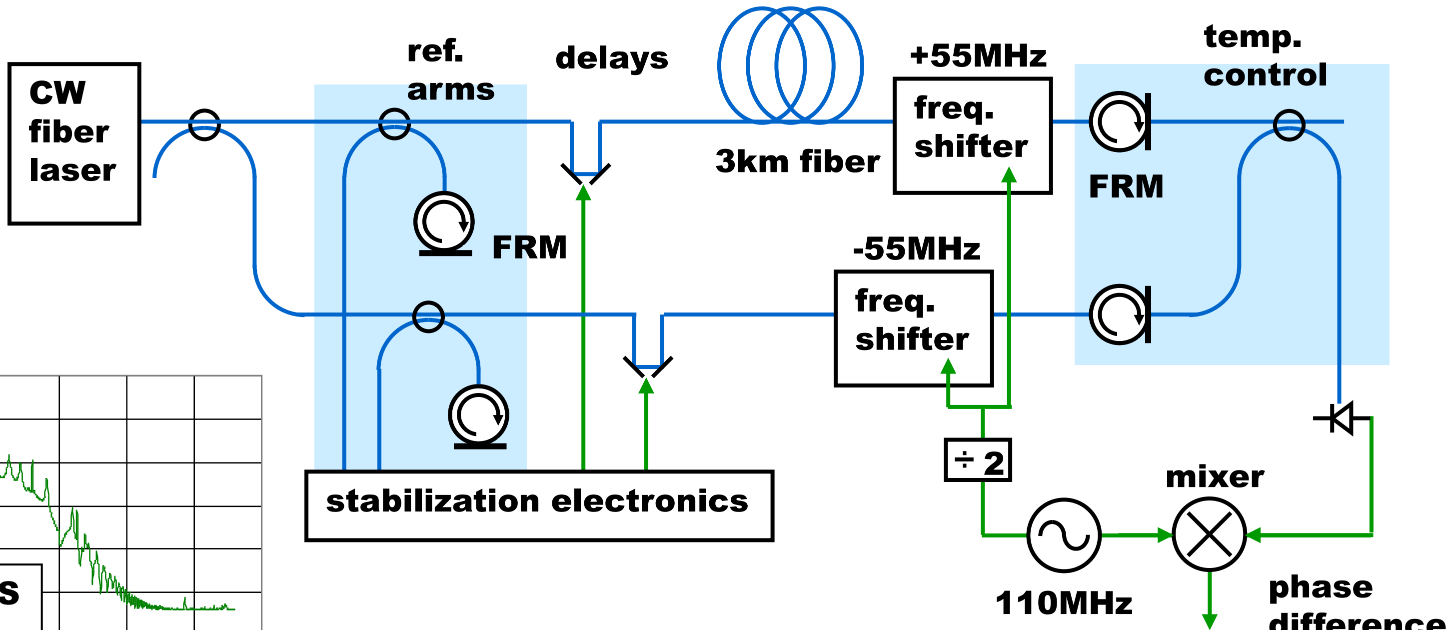
Opt. Lett. 31, 1951 (2006)

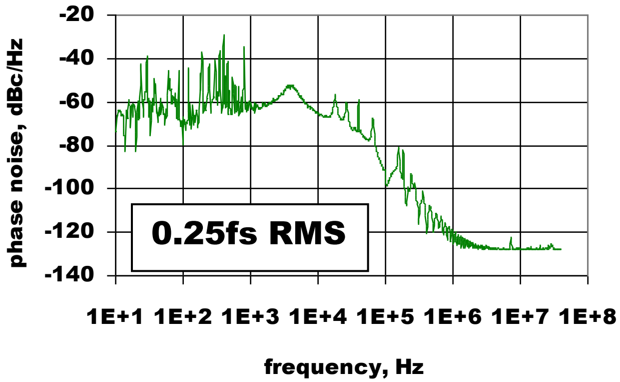


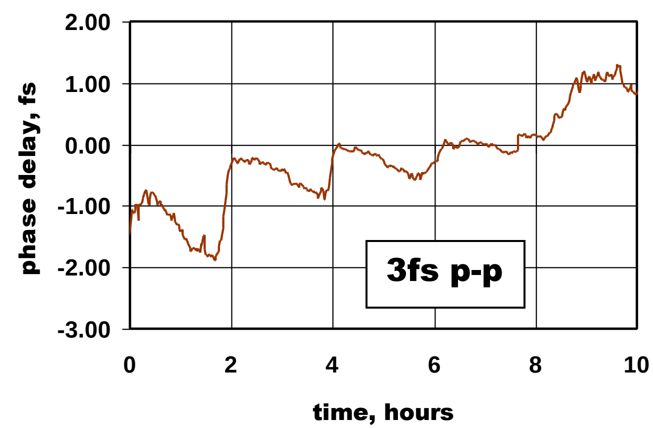
- Hudson et al at JILA/NIST
  - 7km fiber, 19fs from 1Hz to 100kHz
  - Phase detection of a high harmonic of pulse repetition rate
  - Metro fiber around Boulder, CO

Opt. Lett. 30, 1225 (2005)

Stabilization using interferometry

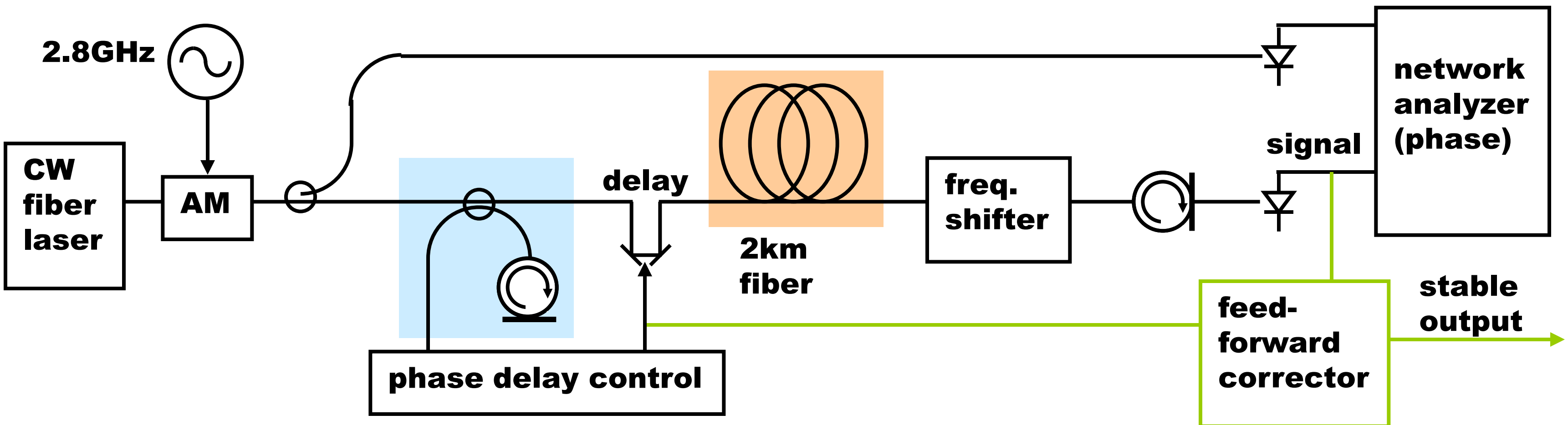


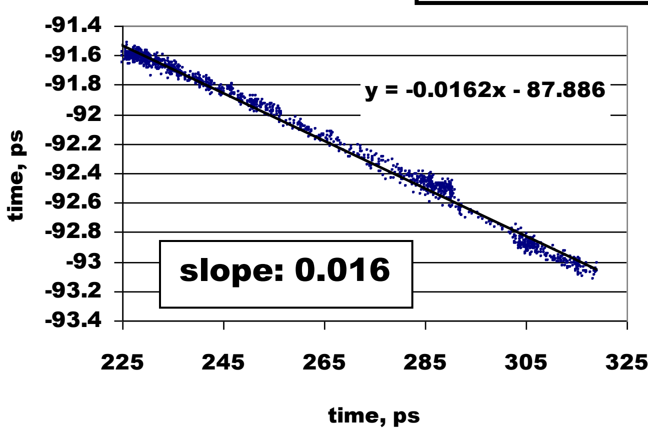


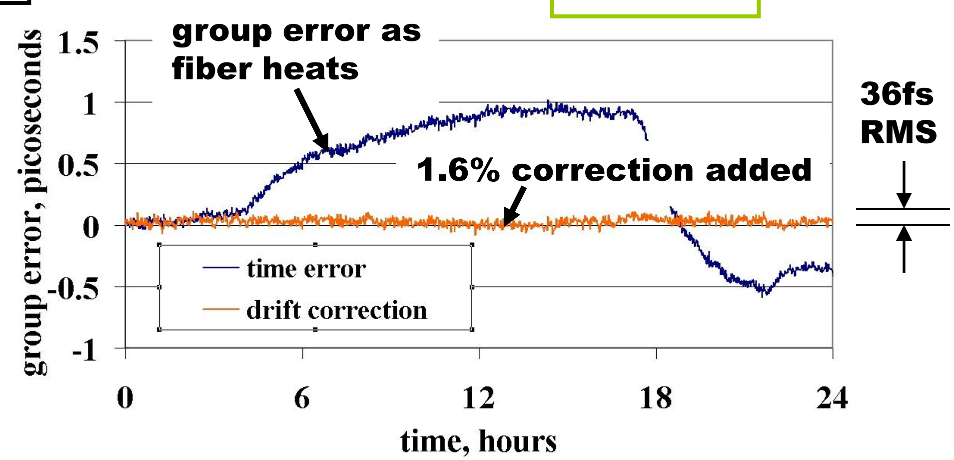


- Wilcox and Staples at LBNL
  - 3km fiber, 0.26fs from 10Hz to 40MHz, 3fs p-p over 10 hours
  - Two interferometrically stabilized fibers in Mach-Zehnder interferometer
  - 2km LAN fiber plus 1km spool

Stabilizing group delay by measuring phase

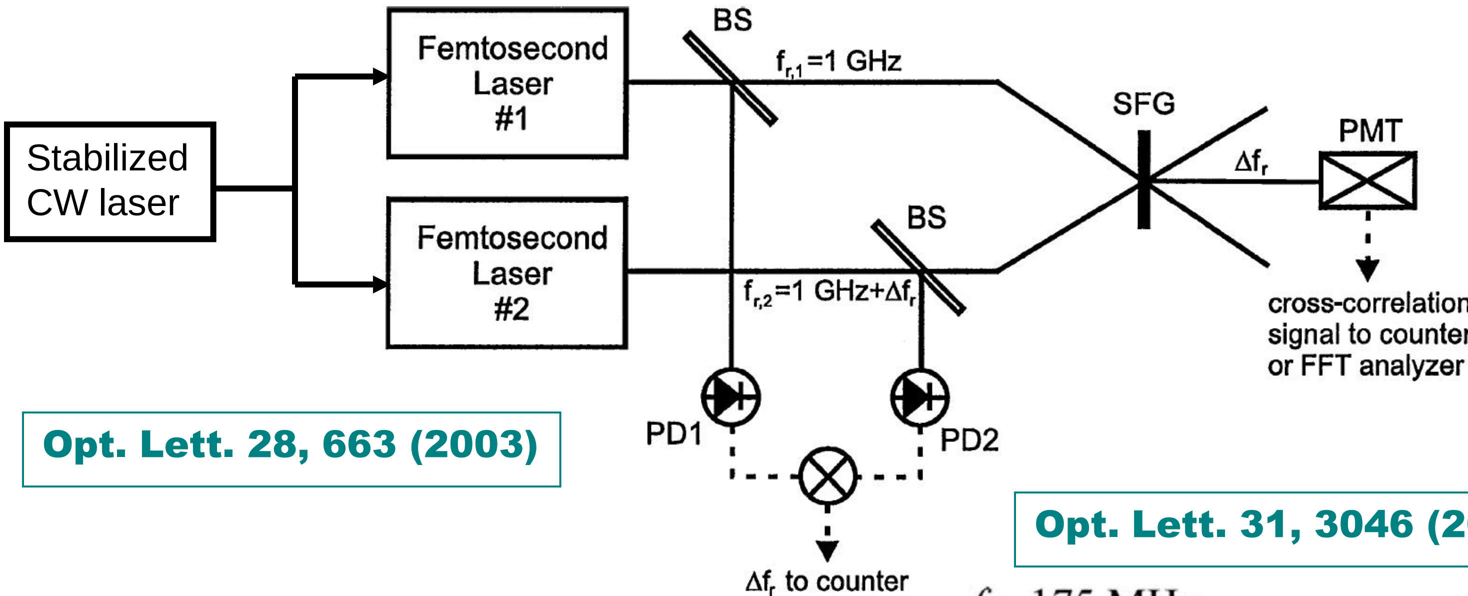






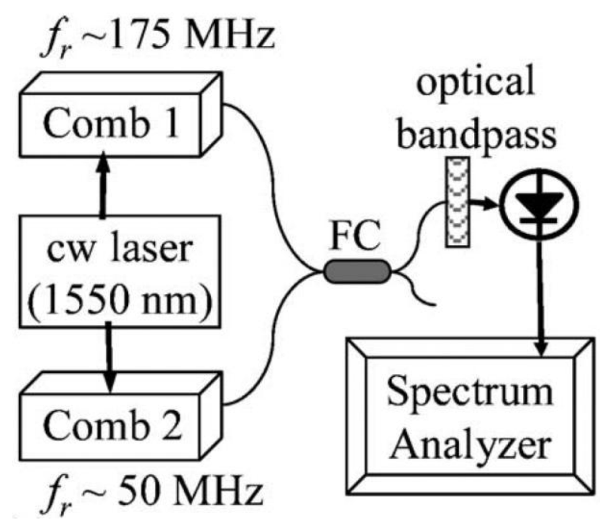
- Wilcox and Staples at LBNL
  - 2km fiber, 36fs over 24 hours (predicted from data)
  - Proves validity of feedforward scheme
  - LAN fiber

One frequency and CEO stabilized lasers



Opt. Lett. 28, 663 (2003)

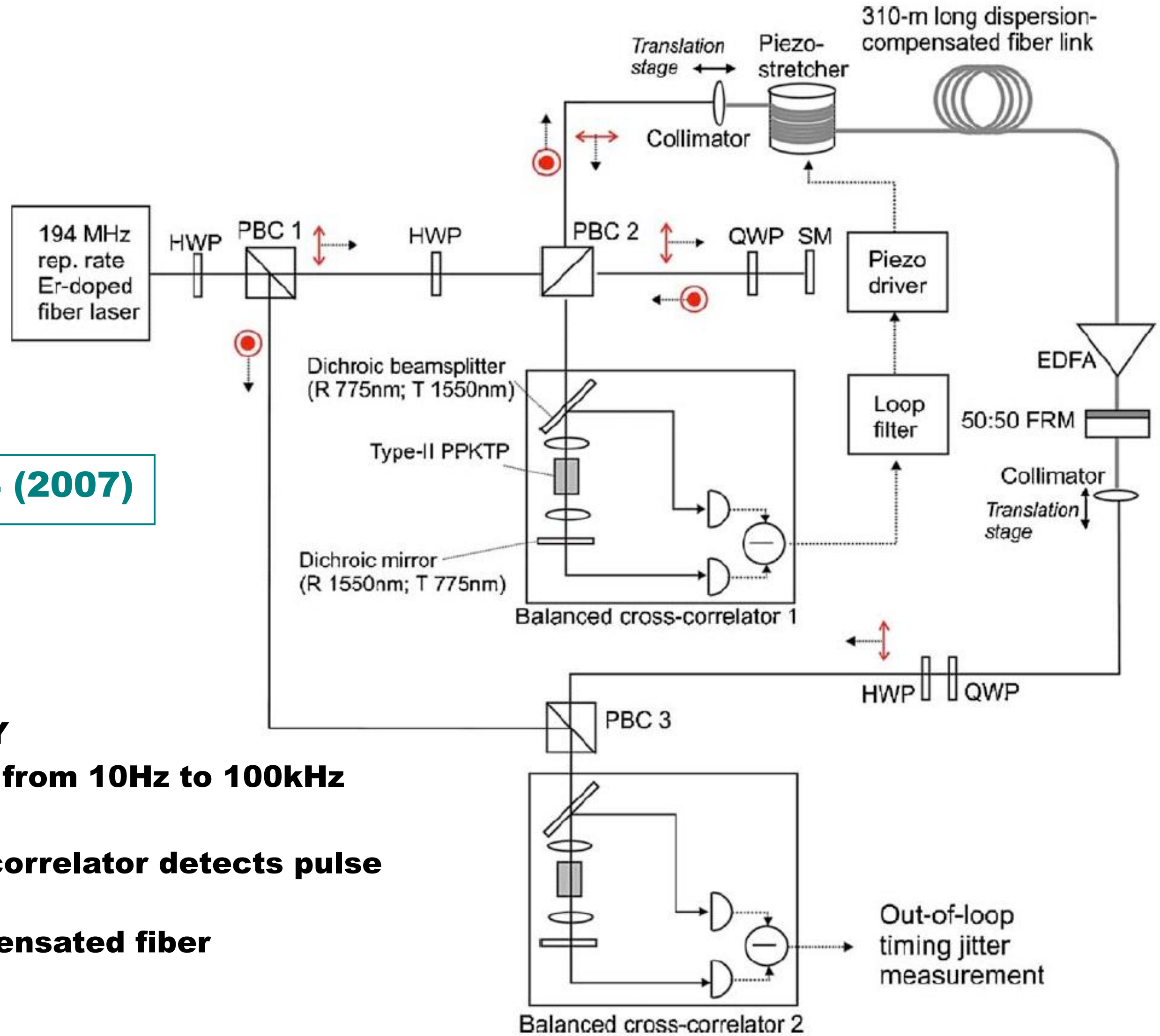
Opt. Lett. 31, 3046 (2006)



- **Bartels et al at NIST**
  - **Adjacent lasers, 1.5fs from 1Hz to 100kHz**
  - **One CW laser heterodyned with comb line of two stabilized lasers**
- **Swann et al at NIST, IMRA, OFS, Stanford**
  - **Adjacent lasers, 0.9fs from 0.06Hz to 500kHz projected, based on beat frequency stability**

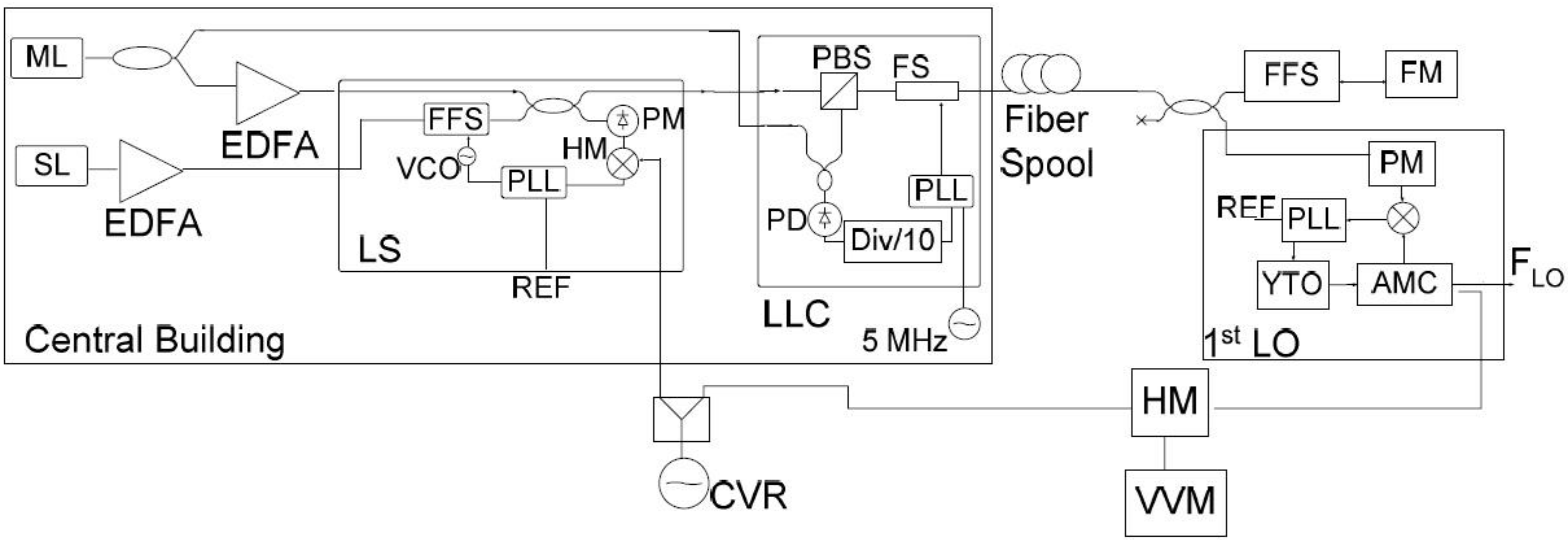
Short pulses + cross correlation

Opt. Lett. 32, 1044 (2007)



- **Kim et al at MIT, DESY**
  - **310m fiber, 9.2fs from 10Hz to 100kHz**
  - **9.7fs over 100s**
  - **Balanced cross-correlator detects pulse train**
  - **Dispersion-compensated fiber**

Interferometer stabilized 2-freq. transmission

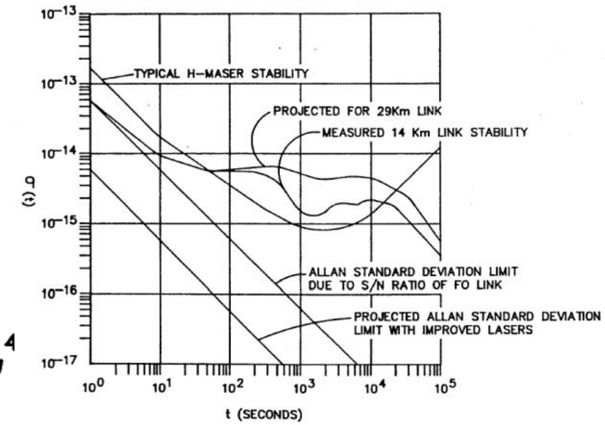


IEEE LEOS Summer Topical 2005
paper TuB4.2

- **Shillue at NRAO/ALMA**
  - **15km fiber; 35fs from 1kHz to 10MHz (sending 81GHz)**
  - **10km fiber; 42fs over 600s (sending 20GHz)**
  - **Interferometrically stabilized fiber, photodiode detects optical beats**
  - **Fiber on spools**

Phase shifting transmitted RF on CW

- Patent number 5,031,234, by Primas, Syndor and Lutes at JPL



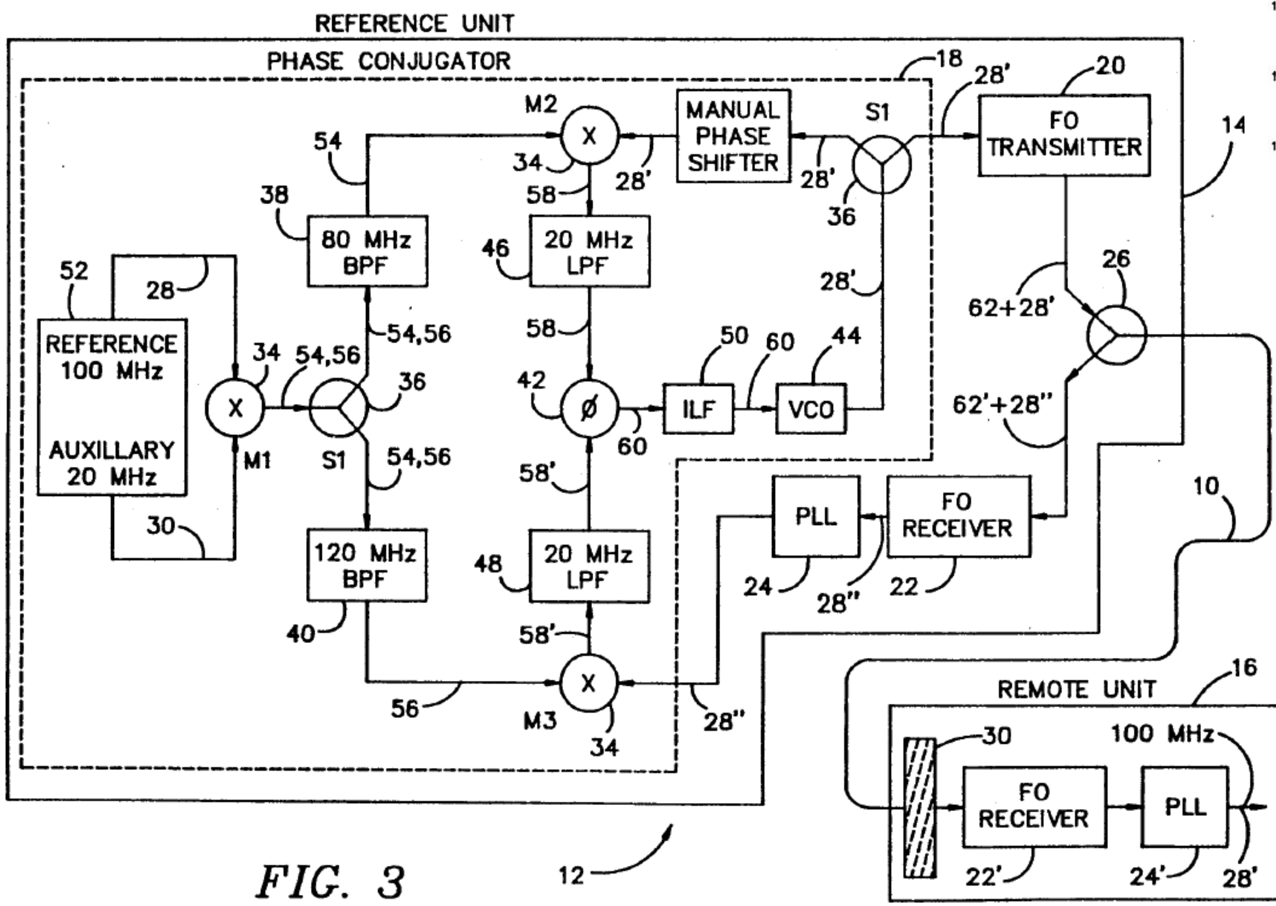


FIG. 3

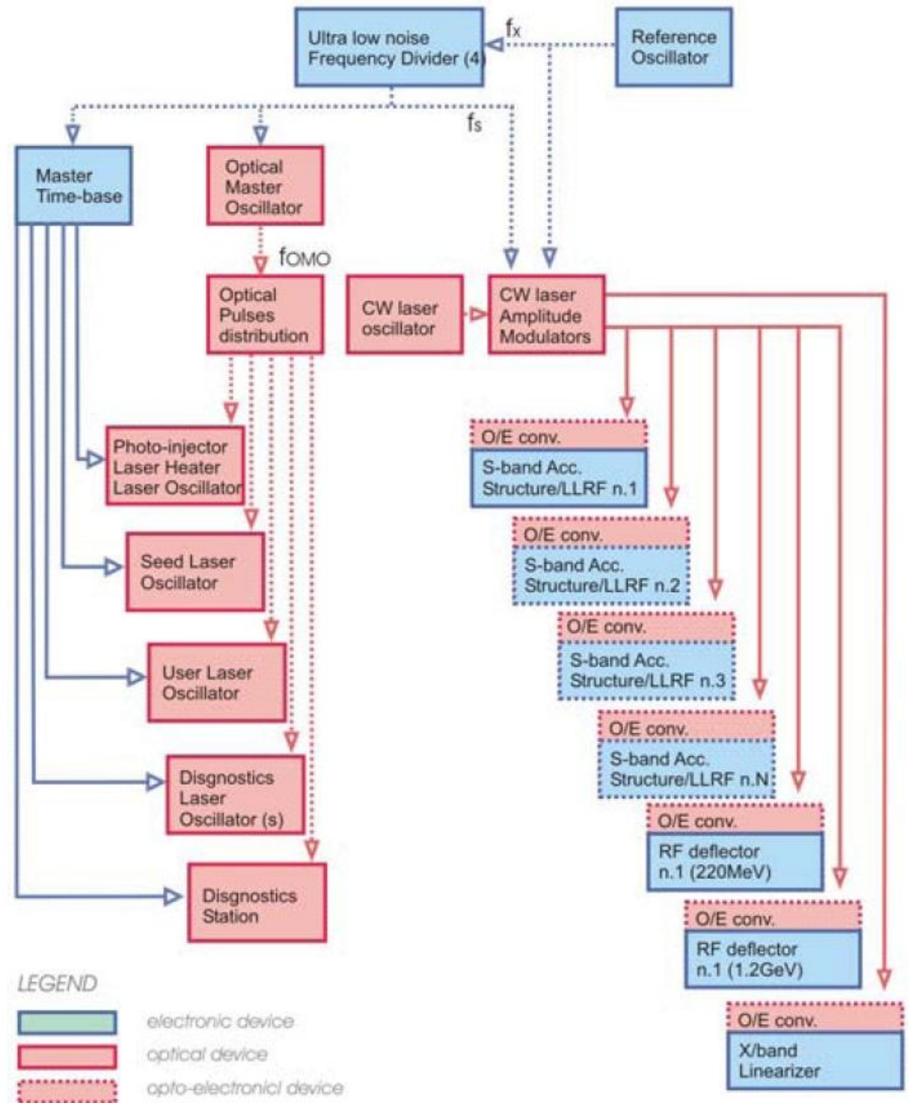
Synch methods are transducers, of a sort

Source \Receiver	RF	Pulsed laser
Modulated RF	Photodiode (AM) Interferometer+PD (FM)	Lock harmonic to detected RF
Pulse train	Detect high RF harmonic of pulse train Electro-optic sampling	Compare high RF harmonics Cross-correlation Amplify transmitted pulses Nonlinear optical lock
Optical CW	Optical difference frequency	One-frequency comb lock Two-frequency comb lock

- This implies a hybrid system can be designed, using different formats together

One system, two methods (labs)

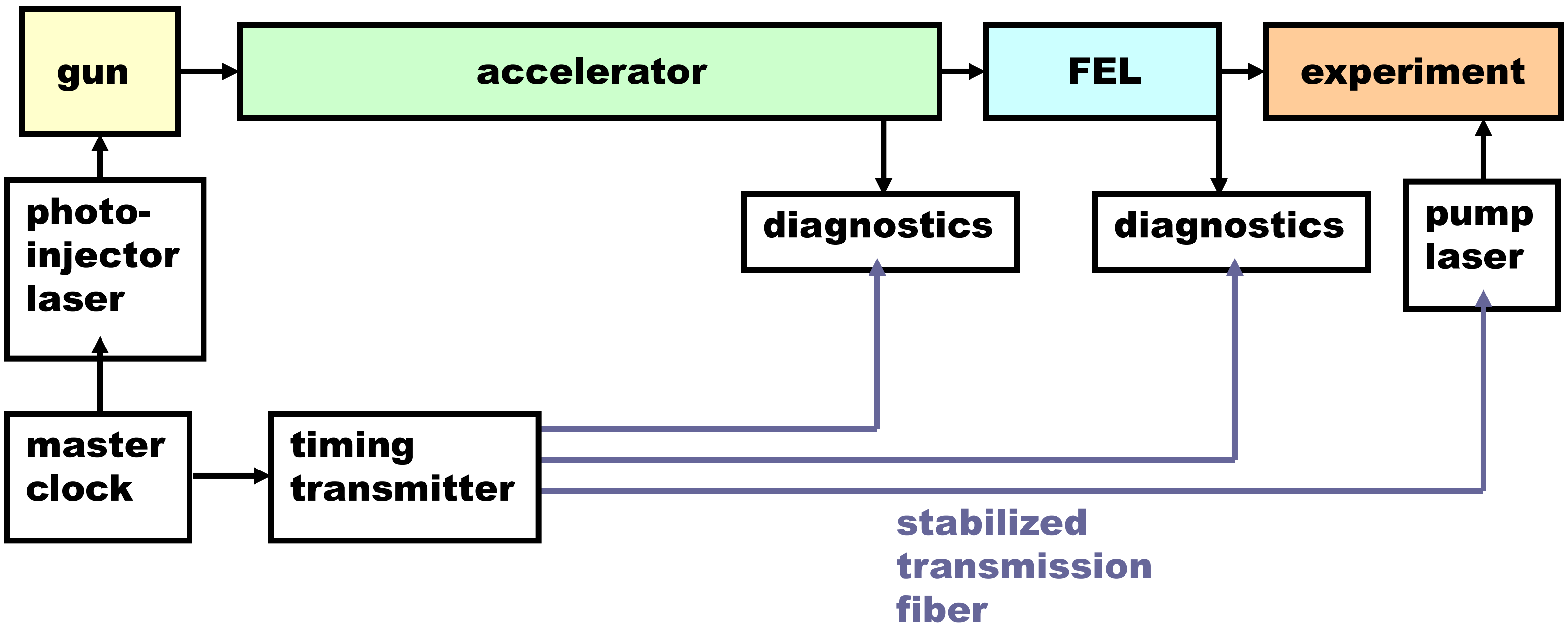
- **Fermi@Elettra conceptual design (CDR)**
- **Pulse train transmission for laser synch (MIT)**
- **AM modulated CW for RF synch (LBNL)**
- **Both systems mutually synchronized by reference RF oscillator**



System architecture

- Star configuration, typically
  - Possible common-mode cancellation by length equalization
    - Reduces long term optical and RF clock stability requirements
    - Could break down if lengths are changed
    - Problem when comparing with another, absolutely stable system
- Power requirements for receiver
  - Loss/gain calculation
  - "Blast and split" architecture used in cable TV
    - Avoids amps in arms, which have lots of PMD
  - Avoidance of nonlinear thresholds
- Possible tree configuration, with multiple senders
- Length of lines determines nonlinear effects, dispersion, loss, length control bandwidth, needed control range

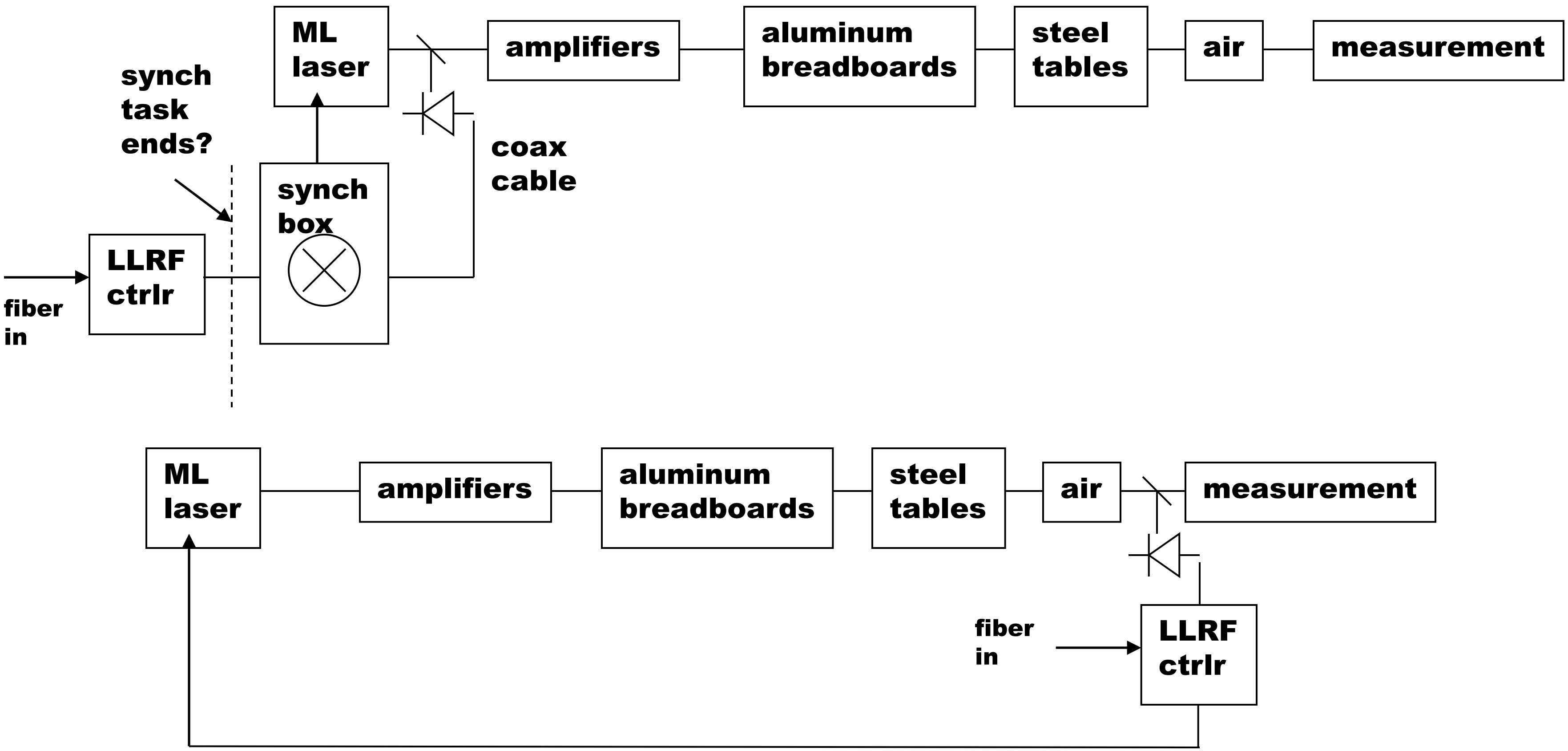
A system currently being designed



- Enable synchronization of lasers in LCLS to <100fs RMS relative time stability, short and long term (1kHz to 12 hours)
- Transmits 2856MHz via fiber, so that lasers can be synchronized to a high harmonic of their repetition rate
- Fibers are delay stabilized over 2km length, in "star" configuration originating from RF reference in photocathode laser room

There's more to do

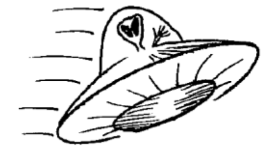
- Only part of the overall problem
  - Laser system delay uncertainty (drift)
    - Close loop around the laser system
  - Accelerator/FEL delay uncertainty (drift)
    - Feedforward length data from around the facility
  - Synch system is key component, providing timing reference and control points



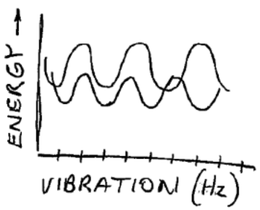
Some relevant books

- Anthony E. Siegman, Lasers, University Science Books 1986
- Govind P. Agrawal, Nonlinear Fiber Optics, Academic Press 1995 (second edition)
- Govind P. Agrawal, Lightwave Technology, Wiley Interscience 2004
- Emmanuel Desurvire, Erbium-Doped Fiber Amplifiers, Wiley 1994
- Walter Koechner, Solid-State Laser Engineering, Springer 1999 (fifth edition)
- Max Born and Emil Wolf, Principles of Optics, Cambridge University Press 1999 (seventh edition)

Other applications of timing control



“Also, Von Neumann was called by the government to come and assist in the examination of a crashed UFO in 1947 at Aztec. Another crash occurred at Aztec about a year later. The first crash had greys on it and none survived. At least one occupant survived the second crash. The radar systems unintentionally brought down the craft. Radar was used intentionally after that until the aliens got wise to it. The occupant of the second crash was not a grey, and Von Neumann got to talk with it. Von Neumann asked it what the answer to the invisibility problems could be. He learned that he had to go back and do his homework in metaphysics. The nature of the problem was that the personnel on the ship were not locked to the zero-time reference of the ship. Humans are normally locked to the point of conception as a time reference, not a zero-time reference. The time stream lock allows the person to flow in synch with the system so interaction is possible.

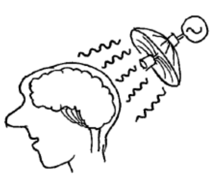


The locks are fragile. All the power of the project disrupted the time-locks of the people on the deck on the ship. When the ship came back in time, the people didn't come back to the same reference.

Von Neumann realized that he needed a computer, as well as some knowledge of metaphysics in order to be able to lock the time reference of the people to the time reference of the ship. He built a computer in 1950 for the purpose. It was ready to be installed in 1952 and a test was performed in 1953 that was successful. They didn't go floating off into space when it was over. At this point, the Navy canceled Project Rainbow and changed the name to project Phoenix.

A lot came out of the negative effects of the Rainbow project. Some of it led to mind control research programs in the Phoenix project. The invisibility research produced some Stealth technology as well as other highly classified projects.

In 1983, they decided to apply mind control to all participants in these projects in an effort to cover them up. They had also been working on another project: age regression. Now, Tesla had sought back in the 1940's to develop equipment that could help the members of the crew after they lost time-lock . The government developed it into the age regression program. It was physical age regression. A person retained the memory they had from the older age.



Tesla's theory was that if you took the individual's time-lock and moved it forward in time then you would remove aging. That's what happened. It took between 30 and 60 days for the body to complete the change to the new time reference.”

- Preston Nichols, on the Montauk project (interview)