R&D Towards a Solid-State Central Tracker in NA

World-Wide Review of LC Tracking
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SCIIPP & UC Santa Cruz
The SD Tracker

Note: No report from Si Drift this time around; status of effort unclear.
Frequency Scanned Interferometer Demonstration System

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Physics Goals and Background

- To Carry out R&D toward a direct, quasi real time and remote way of measuring positions of critical tracker detector elements during operation.
- The 1-Dimension accuracy of absolute distance is on the order of 1 micron.
- Basic idea: To measure hundreds of absolute point-to-point distances of tracker elements in 3 dimensions by using an array of optical beams split from a central laser. Absolute distances are determined by scanning the laser frequency and counting interference fringes.
- Assumption: Thermal drifts in tracker detector on time scales too short to collect adequate data samples to make precise alignment.

Background – some optical alignment systems

- RASNIK system: used in L3, CHORUS and CDF
- Frequency Scanned Interferometer(FSI): used in ATLAS
  
  [A.F. Fox-Murphy et al., NIM A383, 229(1996)]

- Focusing here on FSI system for NLC tracker detector
Principle of Distance Measurement

The measured distance can be expressed by

\[ R = \frac{c\Delta N}{2n_g\Delta \nu} + \text{constant end corrections} \]

- \( c \) - speed of light, \( \Delta N \) – No. of fringes, \( \Delta \nu \) - scanned frequency
- \( n_g \) – average refractive index of ambient atmosphere

Assuming the error of refractive index is small, the measured precision is given by:

\[ (\sigma_R / R)^2 = (\sigma_{\Delta N} / \Delta N)^2 + (\sigma_{\Delta \nu} / \Delta \nu)^2 \]

Example: \( R = 1.0 \text{ m}, \Delta \nu = 6.6 \text{ THz}, \Delta N \sim 2R\Delta \nu/c = 44000 \)

To obtain \( \sigma_R \approx 1.0 \mu \text{m} \), Requirements: \( \sigma_{\Delta N} \sim 0.02, \sigma_{\Delta \nu} \sim 3 \text{ MHz} \)
FSI Demonstration System In Lab

Photodetector

Retroreflector

Mirror

Beamsplitters

Laser

Fabry-Perot Interferometer
Absolute Distance Measurements

- The measurement spread of 30 sequential scans performed vs. number of measurements/scan ($N_{\text{meas}}$) shown below. The scanning rate was 0.5 nm/s and the sampling rate was 125 KS/s. It can be seen that the distance errors decrease with increasing $N_{\text{meas}}$. If $N_{\text{meas}} = 2000$, the standard deviation (RMS) of distance measurements is **35 nm**, the average value of measured distances is **706451.565 µm**. The relative accuracy is **50 ppb**.
Error Estimations

- Error from uncertainties of fringe and frequency determination, \( dR/R \sim 1.1 \text{ ppm} \); if \( N_{\text{meas}} = 2000 \), \( dR/R \sim 24 \text{ ppb} \)
- Error from vibration. \( dR/R \sim 0.4 \text{ ppm} \); if \( N_{\text{meas}} = 2000 \), \( dR/R \sim 8 \text{ ppb} \)
- Error from thermal drift. Temperature fluctuations are well controlled down to 0.5 mK (RMS) in Lab by plastic box on optical table and PVC pipes shielding the volume of air near the laser beam. An air temperature change of 1 °C will result in a 0.9 ppm change of refractive index at room temperature. The drift will be magnified during scanning. \( dR/R \sim 30 \text{ ppb} \); if \( N_{\text{meas}} = 2000 \), \( dR/R \) is increased to \( \sim 40 \text{ ppb} \) because the measurement window size is smaller for larger \( N_{\text{meas}} \).
- Error from air humidity, \( dR/R \sim 10 \text{ ppb} \). Error from barometric pressure should have negligible effect on distance measurement.

The total error from the above sources is \( \sim 48 \text{ ppb} \) which agrees well with the measured residual spread of 50 ppb.
Summary and Outlook

- A simple FSI demonstration system was constructed to make high-precision absolute distance measurements.
- A high accuracy of 35 nm for a distance of about 0.7 meter under laboratory conditions was achieved.
- Two new multi-distance-measurement analysis techniques were presented to improve absolute distance measurement and to extract the amplitude and frequency of vibration.
- Major error sources were estimated, and the expected error was in good agreement with measured residual spread from real data.
- One paper, ‘High-precision Absolute Distance Measurement using Frequency Scanned Interferometer’, will be submitted to Optics Letters.
Summary and Outlook

- We are working on FSI with fibers, one fiber for beam delivery and the other fiber for return beam. Much work needed before practical application of FSI system. Fibers necessary for remote inner tracker interferometer.
- The technique shown here does NOT give comparable accuracy under realistic detector conditions (poorly controlled temperature).
- Will investigate Oxford ATLAS group’s dual-laser scanning technique.
- Michigan group rapidly coming up to speed on technology, but much work lies ahead.
The SCIPP/UCSC Long Shaping-Time Effort

Faculty/Senior
Alex Grillo
Hartmut Sadrozinski
Bruce Schumm
Abe Seiden

Post-Doc
Gavin Nesom
Jurgen Kroseberg

Student
Christian Flacco
(will do BaBar thesis)

Engineer: Ned Spencer (on SCIPP base program)
Pulse Development Simulation

Long Shaping-Time Limit: strip sees signal if and only if hole is collected onto strip (no electrostatic coupling to neighboring strips)

Incorporates: Landau statistics (SSSimSide; Gerry Lynch LBNL), detector geometry and orientation, diffusion and space-charge, Lorentz angle, electronic response
Result: S/N for 167cm Ladder

At shaping time of 3\(\mu\)s; 0.5 \(\mu\)m process qualified by GLAST
Analog Readout Scheme: Time-Over Threshold (TOT)

\[ \theta = \frac{n_e^{\text{thresh}}}{<n_e>_{\text{min-i}}} \quad r = \frac{n_e^{\text{pulse}}}{<n_e>_{\text{min-i}}} \]

TOT given by difference between two solutions to

\[ \theta = \frac{et}{r} \quad \frac{e^{-t/\tau}}{\tau} \]

(RC-CR shaper)

Digitize with granularity \( \tau/n_{\text{dig}} \)
Why Time-Over-Threshold?

With TOT analog readout:

Live-time for 100x dynamic range is about $9\tau$

With $\tau = 3 \, \mu s$, this leads to a live-time of about $30 \, \mu s$, and a duty cycle of about $1/250$

→ Sufficient for power-cycling!

Signal/Threshold $= (\theta/r)^{-1}$
Single-Hit Resolution

Design performance assumes 7$\mu$m single-hit resolution. What can we really expect?

- Implement nearest-neighbor clustering algorithm
- Digitize time-over-threshold response ($0.1^{*}\tau$ more than adequate to avoid degradation)
- Explore use of second `readout threshold’ that is set lower than `triggering threshold’; major design implication
Resolution With and Without Second (Readout) Threshold

Resolution vs. Readout Threshold: Length = 167cm, Trg = 0.23

- 167cm Ladder

Resolution vs. Readout Threshold: Length = 132cm, Trg = 0.23

- 132cm Ladder

Readout Threshold (Fraction of min-i)
Based on simulation results, ASIC design will incorporate:

- 3 $\mu$s shaping-time for preamplifier
- Time-over-threshold analog treatment
- Dual-discriminator architecture

The design of this ASIC is now underway.
Challenges

Cycling power quickly is major design challenge

Warm machine: At 120 Hz, must conduct business in ~150 µs to achieve 98% power reduction

What happens when amplifier is switched off?

Drift of ~10 mV (or 1 fC in terms of charge) enough to fake signal when amp switched back on

Challenging for circuit design
More Challenges

Trying to reach dynamic range of >100 MIP to allow for dEdX measurement of exotic heavy particles.

At comparitor, MIP is about 500 mV, rail is about 1V.

Active `Ramp Control' forces current back against signal for few MIP and greater.
Response to signals between $\frac{1}{4}$ and 128 mips (in factor-of-two octaves)
Response to ¼, 1 and 4 mip signals

8 msec power-off period (not to scale)

60 msec power restoration

Power Off

Power On

Response to ¼, 1 and 4 mip signals
Looking ahead

Challenges continue to arise in circuit design (but at least they’re being caught before the chip is made!)

Layout in specific technology (0.25 µm mixed-signal RF process from Taiwan Semiconductor) lies ahead; substantial experience at SLAC and within UCSC School of Engineering ➔ Submit in March?

Long ladder, Nd:YAG pulsing system, readout under development

Project is very challenging, but progress is being made, albeit slower than first envisioned.