Fast Timing Workshop

Krakow, Nov 29 - Dec 1st 2010

- 9 sessions

Industry well represented: Photek, Philips

Louvain, Fermilab, BNL, Orsay, Saclay, Hawai'i, Chicago,

Warsaw, Krakow, GSI, CERN, Alberta, Nagoya, Yerevan
The Workshop topics (P. Le Du)

- **Photodetectors**
  - Initially MCP’s
    - Development of large MCP’s (LAPD project)
    - But it is interesting this time to heard about timing performance of solid state devices like MPPC/SiPM.

- **Electronics, Read out and Trigger**
  - Fast Digitizers (10-25 psec)
    - Sampling ASIC, TDC ...
  - System aspect when large number of pixellated channels

- **Improvement of Time Of Flight (TOF) technique**

- **Application in multidisciplinary environment**
  - HEP, NP and Astro (1 to 50 psec)
    - LHC forward physics, new b Factories, Muons, neutrino, FAIR,
    - future SLHC, ILC/CLIC
  - Medical Imaging (50-250 psec)
    - TOF-PET, Real Time PET for Hadron-therapy ….
Last IEEE NSS-MIC highlights (Knoxville, TN) - Nov 2010

- Progress in scintillators
  - see Paul Lecoq and Marek Moszynski talks
- Photodetectors (3 sessions)
  - a SiPM/MPPC/APD array festival
  - A lot of industrial development
- Electronics
  - Not much compare to the Clermont workshop
- Applications
  - Si-PET & TOF-PET
Next generation photomultipliers

- **History**

- (TV idea 1907... 1st PMT: 1934, S1, Tele-movies 1936)
- 1945 Sommer: 1st high gain PMT, RCA, EEV 1953
- RCA sold technology to Hamamatsu

- **MCPs**

  Idea: 1930 Farnworth
  First: 1960 Oscheopkov
# Checklist for Next Generation PMT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MCP</th>
<th>ALD/MCP</th>
<th>Diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Stage Gain</td>
<td>1.8?</td>
<td>4 ?</td>
<td>50</td>
</tr>
<tr>
<td>Counting Efficiency</td>
<td>60%</td>
<td>80%?</td>
<td>80%?</td>
</tr>
<tr>
<td>Timing</td>
<td>10ps</td>
<td>tbc</td>
<td>50 ps</td>
</tr>
<tr>
<td>Life Issues</td>
<td>Severe</td>
<td>tbd</td>
<td>Some promise</td>
</tr>
<tr>
<td>Count Rate</td>
<td>10 MHz/cm²</td>
<td>Similar to other MCP?</td>
<td>Should be very High Rate</td>
</tr>
<tr>
<td>Magnetic Immunity</td>
<td>Evidence of Immunity</td>
<td>Similar to standard?</td>
<td>Experiments needed</td>
</tr>
</tbody>
</table>
Diamond at Photek

Diamond fast due to strong band bending (high E field)

Collaboration with Bristol Uni; STFC (Rutherford); AWE; Leicester Uni & Photek started 2009

Gain from Bristol material is as good/better than US

Operational life testing shows good gain stability and little cathode damage

Micro machined parts to 50µm being made

Plans for 20µm for next step
Negative Electron Affinity Dynodes - The Next Generation?

<table>
<thead>
<tr>
<th>Material</th>
<th>Date</th>
<th>Gain</th>
<th>Timing</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>1970 (RCA)</td>
<td>900</td>
<td>50 ns</td>
<td>High Dark Noise</td>
</tr>
<tr>
<td>Silicon</td>
<td>1972 (EEV)</td>
<td>2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaAs</td>
<td>1972 (NVEOL)</td>
<td>900</td>
<td>≤1 ns</td>
<td>In-situ heat clean to 600°C</td>
</tr>
<tr>
<td>GaP</td>
<td>1972 (RCA)</td>
<td>30</td>
<td>≤1 ns</td>
<td>Used in high DQE PMTs</td>
</tr>
<tr>
<td>Diamond</td>
<td>1994 (RCA)</td>
<td>50</td>
<td>50 ps</td>
<td>Replaces GaP as first dynode</td>
</tr>
</tbody>
</table>
Multi-anode and Imaging pico-second development (T. Conneely)

Electronics

CERN

- Nino ampli/discri: TOT concept, LVDS like output, jitter 10ps
  Max rate 10 MHz

- HPTDC: 32 channel at 100ps binning
  8 channels at 25ps
Multi-anode and Imaging pico-second development (T. Conneely)

3-micron MCPs tube

- 8 x 8 multi-anode, 16 x 16 mm² active area
- Two 3-micron pores MCPs
- 8 x 8 capacitively coupled pads
- Fast analogue electronics → high event rates

Read with Nino/HPTDC
- Nino board

Results:

78ps – 65 ps (delay generator jitter) = 43 ps
includes laser jitter (40 ps duration)
Neutron Irradiated bulk GaAs has a short carrier lifetime comparable with LTG GaAs. Poor electrical properties (especially the resistivity) might rule out it from practical device application (it turns into high dark current and not sufficient sensitivity)

Neutron irradiation should decrease carrier lifetime of LTG GaAs and it is very likely that good electrical properties will not be sacrificed

Nitrogen implantation of LTG GaAs
(I have already received implanted samples from ITME Polish institute of electronic materials technology)

Bi$^+$ and Sb$^+$ implantation might shifts the band-gap of LTG GaAs towards 0.8 eV (anticrossing valance band model)
Electro Optics Sampling measurement results

GaAs 1 2 2
$\lambda = 795 \text{nm}$

$P_i = 5 \text{ mW}$

Bias Voltages
- 0 V
- 5 V
- 10 V
- 15 V
- 20 V
- 25 V
- 30 V

Response [V]

Time delay [ps]
The single electron project, S. White, BNL

- ATF beam is 3 picosec bunch length, exploited to evaluate fast timing detectors?
- Common technique for secondary beam design is successive dispersion and collimation

- Single 100 MeV electron scattered at 90deg into a 1cm2 detector at 30cm

- Deep diffused APD to reject background noise: 650 ps rise-time, Al target changed for Be, better results

- DAQ: Waveform sampling with scope and DRS4

- Growing interest in Nuclear and HEP in timing detectors with ~10 ps time resolution. ie extension of pid to new kinematic region in PHENIX

- Pileup rejection at the LHC in forward physics (LHC bunch interaction rms=170 ps)

- New progress in timing possible similar to Si tracking of last 20 years
The single electron project, S. White, BNL

Driver for faster timing @LHC is leading protons @L=10^{34}
Look for new technologies that survive full Luminosity.
Hamamatsu (M. Suyama) provided a new device for evaluation.
Lifetime tests show >250 Coulomb/cm^2 (cp. MCP, 20%loss @0.1Coulomb).
The single electron project, S. White, BNL

Shannon-Nyquist Reconstruction:

Waveform sampling at $2 \times \text{max(spectrum)}$, Interpolate with sinc filters, derive intersect to zero
RF phototube + optical clock = 3H timing technique for single photons

Schematic layout of the synchroscan mode of RF phototube with optical clock.

Optical Clock is used as a source of RF frequencies to operate the RF phototube and as a reference photon beam to minimize or exclude the time drifts due to RF synthesizer and phototube.

Time precision determined by single photon time resolution and statistics !!!

A. Margaryan, article in press, doi: 10.1016/j. nima, 2010.08.122

20ps for single PE
Femtosecond Optical Frequency Comb as a multipurpose frequency synthesizer

Fractional instability of optical clocks $\rightarrow 10^{-18}$
Fractional instability of rf synthesizer $< 20 \text{fs} / \tau$

Depicted from T. M. Ramond et al., 2003
Amur Margaryan, Yerevan

Design and Control of Femtosecond Lasers for Optical Clocks and the Synthesis of Low-Noise Optical and Microwave Signals

Scott A. Diddams, Albrecht Bartels, Tanya M. Ramond, Chris W. Oates, S. Bize, E. A. Curtis, J. C. Bergquist, and Leo Hollberg, Associate Member, IEEE

Abstract—This paper describes recent advances in the design and control of femtosecond laser comb for their use in optical clocks and in the synthesis of low-noise microwave and optical signals. The authors present a compact and technically simple femtosecond laser that directly emits a broad continuum and shows that it can operate continuously on the timescale of days as the phase-coherent “clockwork” of an optical clock. They further demonstrate phase-locking of an octave-spanning frequency comb to an optical frequency standard at the millihertz level. As verified through heterodyne measurements with an independent optical frequency standard, this provides a network of narrow optical modes with linewidths at the level of \( \leq 150 \text{ Hz} \), presently limited by measurement noise. Finally, they summarize their progress in using the femtosecond laser comb to transfer the stability and low phase-noise optical oscillators to the microwave domain.

Index Terms—Frequency metrology, frequency synthesis, optical clocks, ultrashort optics, and lasers.

I. INTRODUCTION

SINCE femtosecond lasers were introduced into the field of optical frequency metrology about four years ago [1], [2], they have become indispensable tools in this exciting and expanding area of research [3]–[5]. It is now widely accepted that mode-locked femtosecond lasers will play a critical role in the next generation of atomic clocks based on optical frequencies [6], [7]. In this role, the femtosecond laser (sometimes in conjunction with nonlinear optical fibers) serves as the “optical clockwork” or “synthesizer” that phase-coherently divides the uncountable rate of optical cycles to a countable microwave frequency for subsequent use and comparison to existing standards. The connection between optical and microwave domains is understood most readily in the frequency domain, where the spectrum of the femtosecond laser consists of a comb of evenly spaced modes with frequencies given by

\[
f_n = n f_r + f_o,
\]

(1)

Here, \( f_r \) is the repetition frequency of the laser (typically 0.1 to 1 GHz), \( n \) is an integer, and \( f_o \) is a common offset frequency—often called the carrier-envelope offset frequency due to dispersion in the laser cavity. We have experimentally tested the validity of (1) [8], as have others [2], [9]–[11], to uncertainties approaching one part in \( 10^{18} \).

With these facts established, we have now begun to turn our attention toward the more practical issue of actually making a robust and reliable optical clockwork that functions in a manner more akin to radio-frequency and microwave synthesizers (e.g., a turnkey device that could readily operate for days and weeks). In spite of its very desirable properties, the nonlinear microstructure fiber used in conjunction with the femtosecond laser is often found to be the weak point when we consider the reliability of present optical clockworks. The recent introduction of lasers that emit octave-spanning spectra directly, and thereby circumvent the need for nonlinear spectral broadening in microstructure fibers, is an important advance toward a more reliable clockwork. Section II of this paper describes our efforts in this direction. We present details of a technically elegant broad-band femtosecond laser with 1-GHz repetition rate and its use as an optical clockwork that does not employ a microstructure optical fiber. As will be shown, this system can be tightly phase locked to an optical oscillator for periods approaching 1 day. With improved thermal control, we expect this could be extended to indefinite periods.

On a second front, we continue to explore new opportunities that arise as our control of the femtosecond laser improves. Specifically, while our earlier work has demonstrated that the associated mode comb of the optical clockwork can be exceedingly stable [8], we now show that we are able to make the linewidth of the elements of the mode comb reproduce that of an optical frequency standard at a level that begins to be interesting (\( \leq 150 \text{ Hz} \)). Tight control of the octave-spanning optical comb means that we can now envision the phase-coherent transfer of not only the stability, but also the linewidth of a very narrow optical oscillator to several hundred thousand comb elements spanning the visible and near infrared spectrum. Such an array of narrow optical oscillators would be a valuable general tool for spectroscopy, and the tight phase control will also be critical for the creation of low-noise microwave signals that are generated by dividing down optical oscillators with the femtosecond optical clockwork. It seems clear that in the near future the ultimate stability and phase noise performance from any electromagnetic oscillator will belong to a laser referenced on an atomic transitions. The challenging task of using the femtosecond laser to transfer the properties of optical oscillators across the optical...
Amur Margaryan, Yerevan

Schematic of the GASTOF Cherenkov with RF phototube
Readout Electronics

Schematic of the Readout Scheme with Multi Pixel Anode

The expected at maximum luminosity 10 MHz rate the RF deflector is distributed among ~100 pixels. Each pixel will operate as an independent PMT with ~0.1 MHz rate.

GASTOF with Radio Frequency Phototube

Intrinsic Time resolution few ps

Rate 10 MHz

Stability < 1 ps/hrs

Ability to detect several ten events in a ns period
Fermilab’s Photodetector Timing Program

The experimental method
Lab measurements of Photek MCP’s
Beam tests of Photek with quartz bar radiators
Lab measurements of Hamamatsu and IRST SiPM’s
Beam test of Hamamatsu SiPM
Electronics development

MCPs, SiPMs
Some bench-test results on Photek 240 MCP

Single Photon Timing Resolution has better performance than multi-photon extrapolation would indicate (40ps instead of 100ps extrapolated).
Fermilab’s Test Beam Facility

- Spacious control room
- Signal, HV cables and gas delivery
- MWPC and silicon pixel trackers
- Three motion tables

Best beam for timing studies is Main Injector 120 GeV monoenergetic beam with 7 mm spot size.
We tested Hamamatsu (Si-PMTs) with different thicknesses of quartz radiator.

Not corrected for electronics (3.1 ps) and PMT240 (7.7 ps) …

Intrinsic resolution of better than 15 ps with 30 mm Quartz.
Waveform analysis of MPPC with DRS4

DRS4: 5 GS/s, four input channels, PC readout thru USB port

Model: charging and discharging of a capacitor: 
\[ p(x) = (1 - \exp(-x/\tau_1)) \cdot \exp(-x/\tau_2) \]

We then convolute this with scintillator decay function and resolution function

1. Fit the leading edge with T, \( \tau_2 \) and resolution fixed

2. Use tangent to the middle of the fit to the leading edge to obtain time stamp (resolution of this method is about 4 psec)

3. Fit the whole pulse to obtain scint decay time T and discharge time \( \tau_2 \)
Time resolution with LSO crystals

- LSO crystals 2x2x7 mm$^3$. Source: $^{60}$Co
- Hamamatsu MPPC 3.5x3.5 mm$^2$
- Clipping capacitor 10 pF on output of the MPPC
- ORTEC preamplifier 120C

Use pulse height analysis to select events from photoelectric peak

Time resolution 140 ps
Summary

- Fermilab has been involved in a long series of timing measurements of various photodetectors and our method, using conventional Ortec electronics, consistently gives <3 psec electronic resolution.

- Lab measurements of Photek 240 give superb performance – ~45 ps single photon timing resolution

- Studies of quartz bar Cerenkov radiators in the beam show that 15 ps level performance TOF is achievable in a variety of conditions

- SiPM studies on the bench show interesting differences in wavelength dependence of timing resolution

- DRS4 digitizer gives very good (~8 ps) electronic resolution in our lab measurements. Fitting of entire LSO pulses with a Co-60 source gives 140 ps
Single Photoelectron timing resolution of SiPMs

Goal: SuperB Forward PID

SiPMs from HPK, SensL (Ireland), FBK (Italy)
Véronique Puill (LAL Orsay)

SiPMs Breakdown voltages

Breakdown voltage of 1 mm² SiPM (25 °C)
Véronique Puill (LAL Orsay)

SiPMs Breakdown voltage

Dark noise: thermally produced avalanches. Look the same as pulses from photon

DCR of 1 mm² SiPM (25°C)

Threshold = 0.5 p.e.
Temperature = 25 °C
Véronique Puill (LAL Orsay)

SiPMs Gain

Defined as the charge developed in one pixel by a primary carrier.

\[ \text{Gain} = \frac{Q_{\text{pixel}}}{e} = \frac{C_{\text{pixel}} \times (V_{\text{bias}} - V_{\text{BD}})}{e} \]

Gain of 1 mm² SiPM (25°C)

5x10⁴ < Gain < 4x10⁶
Véronique Puill (LAL Orsay)

SiPMs Single PE Timing resolution

**SPTR 1 mm² SiPM - 20 °C - 467 nm**

![Graph showing FWHM vs Vbias-VBD (V) for different SiPMs and MPPCs.]

- S10362-11-25
- S10362-11-50
- S10362-11-100
- MPPC-BK-4S (50 μm)
- MPPC 10-100-FS (100 μm)
- FBK B13
- SPM 20
- SPM 50

FWHM (ps) vs Vbias-VBD (V)
Towards picosecond time measurement using fast analog memories

- Using fast analog memories for precise time measurement [D. Breton].
- The WaveCatcher module: description and performances. Comparison with high-end standard electronics for MCPPMT characterization (NIM paper) [J. Maalmi].
- New SCA circuits and ongoing developments by IRFU/LAL team [D. Breton for E. Delagnes].
- Developments towards large scale implementation of analog memories for precise time measurement [D. Breton].
Why Analog Memories?

• Analog memories actually look like perfect candidates for high precision time measurements at high scale:
  – Like ADCs they catch the signal waveform (this can also be very useful for debug)
  – There is no need for precise discriminators
  – TDC is built-in (position in the memory gives the time)
  – Only the useful information is digitized (vs ADCs) => low power
  – Any type of digital processing can be used
  – Only a few samples/hit are necessary => this limits the dead time
  – Simultaneous write/read operation is feasible, which may further reduces the dead time if necessary

• But they have to be carefully designed to reach the necessary level of performance …
  1. Maximize dynamic range and minimize signal distortion.
  3. Minimize costs (both for development & production):
     Use of inexpensive pure CMOS technologies (0.8\(\mu\)m then 0.35\(\mu\)m);
     Use of packaged chips (cheap QFP).
About ADCs …

- An ADC converts an instantaneous voltage into digital value.
- It is characterized by:
  - Its signal bandwidth
  - Its sampling frequency
  - Its number of bits (converted / effective)
  - Collateral damages: Their package, consumed power, output data rate!

- The most powerful products on the market:
  - 8bits => 3GS/s, 1.9 W => 24Gbits/s,
  - 10 bits => 3GS/s, 3.6 W => 30Gbits/s
  - 12 bits => 3.6GS/s, 4.1 W => 43.2Gbits/s
  - 14 bits => 400MS/s, 2.5 W => 5.6Gbits/s
- => appearance of integrated circular buffers (limited by technology)

- Big companies are experts => our only potential benefit to design ADCs is to integrate them within more complex circuits
- The simplest and least power consuming: ramp ADCs (Wilkinson) but they are slow => not adapted to high counting rates

BGA
292 pins
24x1,8Gbits/s
XMC-1151: 56 GSPS 8-bit dual ADC for 40G/100G communications systems

The ultimate!
Pb: different possible paths for data
⇒ need for calibration
⇒ need for knowledge of which path was used
Summary of performances of the SAM chip.

<table>
<thead>
<tr>
<th>NAME</th>
<th>SAM</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption</td>
<td>300</td>
<td>mW</td>
</tr>
<tr>
<td>Sampling Freq. Range</td>
<td>&gt; 3.2</td>
<td>GS/s</td>
</tr>
<tr>
<td>Analog Bandwidth – Full Range (2.5V) – 300 mV pp</td>
<td>450 530</td>
<td>MHz</td>
</tr>
<tr>
<td>Read Out time for whole chip (2 x 256 cells)</td>
<td>&lt; 30</td>
<td>µs</td>
</tr>
<tr>
<td>Fixed Pattern noise</td>
<td>0.4</td>
<td>mV rms</td>
</tr>
<tr>
<td>Total noise (constant with frequency)</td>
<td>0.65</td>
<td>mV rms</td>
</tr>
<tr>
<td>Maximum signal</td>
<td>2 x 2.5</td>
<td>V</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>12.6</td>
<td>bits</td>
</tr>
<tr>
<td>Crosstalk</td>
<td>&lt; 3</td>
<td>per mil</td>
</tr>
<tr>
<td>Relative non linearity</td>
<td>&lt; 1</td>
<td>%</td>
</tr>
<tr>
<td>Equivalent sampling Jitter – without time correction</td>
<td>~ 20</td>
<td>ps rms</td>
</tr>
<tr>
<td>– with time correction</td>
<td>~ 10</td>
<td></td>
</tr>
</tbody>
</table>
The WaveCatcher module : description and performances.

Comparison with high-end standard electronics for MCPPMT characterization (NIM paper).

Jihane Maalmi
Jitter sources

1. **Noise**: depends on the bandwidth of the system
   => converts into jitter with the signal slope

2. **Sampling jitter**: due to **clock Jitter** and to **mismatches** of elements in the delay chain.
   => induces dispersion of delay durations

2.1 Random fluctuations: **Random Aperture Jitter**(RAJ)
   - **Clock Jitter** + **Delay Line**

2.2 Fixed pattern fluctuations: **Fixed Pattern Jitter**(FPJ)
   => systematic error in the sampling time
   => can be corrected thanks to an original method based on a simple 70MHz/1.4Vp-p sinewave (10,000 events => ~ 1.5 min/ch)
Methods to extract time

- Preferred: digital CFD vs Chi2 due to simpler digital implementation on FPGAs
- Chi2 only 10% better.

Very detailed analysis and results by Jihane
See slides
Pulses on different channels: CFD method

- Source: asynchronous pulse sent to the two channels with cables of different lengths or via a generator with programmable distance.
- Time difference between the two pulses extracted by CFD method.
- Threshold determined by polynomial interpolation of the neighboring points.

\[ \sigma_{\Delta t} \sim 10 \text{ps rms} \]

jitter for each pulse \(~ 10/\sqrt{2} \sim 7 \text{ ps}\)

Spline, extraction of the baseline, and normalization

Other method used: \( \text{Chi}^2 \) algorithm based on reference pulses.
Time measurement results: Example with $\Delta t \sim 0$

WaveCatcher V4: 2 pulses with $T_r = T_f = 1.6\text{ns}$ and $\text{FWHM} = 5\text{ns}$  
Distance between pulses: $\Delta t \sim 0$

Differential jitter = 4.61ps $\Rightarrow$ sampling jitter $\sim 3$ ps

All matrix positions are hit!
Effect of CFD ratio on time precision

WaveCatcher V4: 2 pulses with $\text{Tr} = \text{Tf} = 1.6\text{ns}$ and $\text{FWHM} = 5\text{ns}$

- $\Delta t \sim 0\text{ ns}$,
- $\Delta t \sim 10\text{ns}$,
- $\Delta t \sim 20\text{ ns}$

Optimum value: corresponds to the maximum slope of the pulse!!
Characterization of 10μm- MCPPMT with the WaveCatcher Board

- Comparison with high-end standard electronics (NIM paper).
Summary of all the test results

- Laser test - Expected resolution (assume sigma_TTS ~ 120 ps)
- Laser test - Ortec 9327 Amp/CFD
- Laser test - Waveform catcher with HPK amp, CFD algorithm
- Laser test - Waveform catcher with HPK amp, chi-sq. algorithm
- SLAC beam test - Ortec 9327 Amp/CFD, HPK amp.
- Fermilab beam test - Ortec 9327 Amp/CFD, HPK amp.
- Laser test - TARGET chip with HPK amp, chi-sq. algorithm
- Laser test TARGET chip with HPK amp, CFD algorithm
Fermilab beam test

To test the adequation of 10μm MCP-PMTs for time of flight measurements
Conditions: ~40pe and low gain (2-3 \(10^4\))
SLAC laser test

Same conditions as for Fermilab test:
40pe and low gain ($2-3 \times 10^4$)

100Hz

WaveCatcher Board

Tektronix oscilloscope
Summary of the WaveCatcher performances.

- 2 DC-coupled 256-deep channels with 50-Ohm active input impedance
- $\pm 1.25V$ dynamic Range, with full range 16-bit individual tunable offsets
- 2 individual pulse generators for test and reflectometry applications.
- On-board charge integration calculation.
- Bandwidth > 500MHz
- Signal/noise ratio: 11.8 bits rms
  (noise = 650 $\mu$V RMS)
- Sampling Frequency: 400MS/s to 3.2GS/s
- Max consumption on +5V: 0.5A

- Absolute time precision in a channel (typical):
  - without INL calibration: <18ps rms (3.2GS/s)
  - after INL calibration <10ps rms (3.2GS/s)
- Relative time precision between channels: <5ps rms.
- Trigger source: software, external, internal, threshold on signals
- Acquisition rate (full events) Up to ~1.5 kHz over 2 full channels
- Acquisition rate (charge mode) Up to ~40 kHz over 2 channels
Conclusion

• The USB Wave Catcher has become a useful demonstrator for the use of matrix analog memories in the field of ps time measurement.
  • Lab timing measurements showed a stable single pulse resolution < 10 ps rms
  • We hope to reach 5ps in the next timing-optimized chip (0.18µm)

• The board has been tested with MCPPMT’s for low-jitter light to time conversion
  • Results confirm previous measurements with 40 photo electrons
  • CFD and Chi2 algorithm give almost the same time resolution:
  • Double pulse resolution ~ 23 ps => single pulse resolution ~ 16 ps

• Even the simplest CFD algorithm can give a good timing resolution
  • Single pulse resolution < 18 ps
  • It can be easily implemented inside an FPGA (our next step)

- Bandwidth, sampling frequency and SNR are the three key factors which have to be adequately defined depending on the signals to measure (hard with very short signals)
  - The memory structure has to be carefully chosen and designed to get a stable INL
New SCA circuits and ongoing developments by IRFU/LAL team.

Dominique Breton for Eric Delagnes
NECTAR0/SAMLONG block diagram

In SAMLONG Chip

---

Analog Memory (SCA)  
1024 cells  
1-3.2GS/s

Slow Control

SCA Sequencer & pointer manager

ADC 20 MHz

Serializer

LVDS outputs
Bandwidth effects on SAMLONG

• Like in SAM, the analog signal lines inside the chip act as delay lines with some attenuation
  - SAMLONG is 4 times longer.
• The resulting pattern is the sum of:
  – a modulo 16 pattern linked to the routing of the signal input and of the input buffer supplies => worse than SAM but ~ understood
  – a V-like shape linked to memory line attenuation (same slope as SAM)
• This pleads for rather short lines …

6% @ 309 MHz

4% @ 309 MHz
<table>
<thead>
<tr>
<th>NAME</th>
<th>SAM</th>
<th>Nectar0 (targeted)</th>
<th>SAMLONG (measured)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption</td>
<td>300</td>
<td>150-300</td>
<td>160-250</td>
<td>mW</td>
</tr>
<tr>
<td>Sampling Freq. Range</td>
<td>&lt;1 to 2.5 (3.2)</td>
<td>1 to 3.2GS/s</td>
<td>0.4 to 3.2GS/s</td>
<td>GS/s</td>
</tr>
<tr>
<td>Analog Bandwidth</td>
<td>250-300 (450MHz)</td>
<td>300 MHz</td>
<td>&gt;350</td>
<td>MHz</td>
</tr>
<tr>
<td>Read Out time for a 16 cell event (2 gains 1- cells)</td>
<td>&lt; 1.5</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>µs</td>
</tr>
<tr>
<td>Fixed Pattern noise</td>
<td>0.4</td>
<td>0.35</td>
<td></td>
<td>mV rms</td>
</tr>
<tr>
<td>Total noise (constant with frequency)</td>
<td>0.65 (0.5mV if FPN cancelled)</td>
<td>&lt;0.8mV</td>
<td>0.65 (0.55mV if FPN cancelled)</td>
<td>mV rms</td>
</tr>
<tr>
<td>Maximum signal (limited by ADC range)</td>
<td>2 (4)</td>
<td>2V</td>
<td>2V (ADC limited)</td>
<td>V</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>&gt;11.6 (12.6)</td>
<td>&gt;11.3</td>
<td>&gt;11.6</td>
<td>bits</td>
</tr>
<tr>
<td>Crosstalk</td>
<td>&lt;3</td>
<td>&lt;3</td>
<td>&lt;3</td>
<td>per mil</td>
</tr>
<tr>
<td>Relative non linearity</td>
<td>&lt; 1</td>
<td>&lt;3</td>
<td>&lt;3</td>
<td>%</td>
</tr>
<tr>
<td>Sampling Jitter</td>
<td>&lt;15</td>
<td>&lt;50</td>
<td>&lt;35</td>
<td>ps rms</td>
</tr>
</tbody>
</table>
R&D with smaller technology

- SAM and SAMLONG are of course limited in frequency by the 0.35µm technology.
- We have been collaborating to the design of a new circuit in the IBM 130nm technology with our colleagues of the University of Chicago and follow their progress with interest.
  - Their goal is to try to improve the time precision thanks to analog memories sampling at very high frequency (target is 20GS/s).
- We would like to soon start the design a new TDC based on the following scheme, where the usual DLL-based TDC structure is boosted by analog memories sampling at high frequencies.
  - We think of using therefore a 0.18µm CMOS technology.
Developments towards large scale implementation of analog memories for precise time measurement.

Dominique Breton
For the two-bar TOF test at SLAC, we decided to build a synchronous sixteen channel acquisition system based on 8 two-channel WaveCatcher V5 boards:

1. The system has to work with a common synchronous clock
   - There we take benefit of the external clock input of the WaveCatcher V5

2. It is self-triggered but it also has to be synchronized with the rest of the CRT
   - Rate of cosmics is low thus computer time tagging of events is adequate (if all computers are finely synchronized)

3. Like the WaveCatcher, data acquisition is based on 480Mbits/s USB.
Experimental setup

16 SMA connectors

Faraday cage

To amplifiers

PM-side harness

Patch panel

Trigger for the electronics crate (QTZ3)

DIRC-like counter

Mirror (could be removed)

Quartz Start counter

Scribe mark (center of the two hodoscopes)

\[ 107.187^\circ - 74.3125^\circ = 32.8625^\circ \]

(from the bottom hodoscope)
In view of SuperB PID TOF, we decided to mount a high speed PMT/SiPM test facility at LAL.

Thus we started building a second crate

- Same as that of SLAC except that the WaveCatcher boards now have an internal gain of 10 and AC coupling
- We also had boards with DC coupling and gain 1 which allowed us to perform thorough time measurements which we had no time to perform before leaving for SLAC
- There is almost no difference in time performance between gain 1 and gain 10 boards because all the elements implied therein are located behind where the gain is applied to the signal
End of first part...