Calibration and Development of Preamplifier for 8-inch Hybrid Photo Detector

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Akimichi Taketa
Kotoyo Hoshina
Background motivation

*A future mega-ton neutrino detectors may give limits of chemical composition of Earth’s core*

*The detector have to have sensitivity around GeV ~ a few ten GeV to see matter effect of oscillation*

*Reconstruction may be severe due to small number of hits*

*The detector must have good resolutions (charge, timing, etc…)*
Why Hybrid Photo Detector (HPD)?

- Next generation photo detector but not too fancy
- Good charge resolution and time resolution
- Requires high voltage (8kV ~ 10kV)
- Has strong temperature dependency

Example pulse heights
There are pros and cons. Let’s check how HPD (Hamamatsu R12112) is good!

- Gain and Charge resolution
- Timing resolution
- Dynamic range
- Noise Rate
- After pulse (not yet finished, skipped today!)

All features listed above except for Noise Rate is affected by the preamplifier and main amplifier. To get maximum performance of R12112, we developed several preamplifiers and main amplifiers.
Overview of Hamamatsu 8-inch HPD (R12112)

operation voltage

* Photo Cathode to Avalanche Diode:  
  8kV ~ 10kV  
  (HV Cont. Voltage 2.8V ~ 3.5V)

* Anode Bias Voltage: 200V ~ 370V  
  (LV Cont. Voltage 0.8V ~ 1.2V)

* Optimum voltage range has strong dependency to operation temperature
A triple handicap of HPD circuit

1. Floating current source
2. Large stray capacitance
3. Non-negligible delay line

All of them are unavoidable

Inside of HPD

This circuit generates

- Large transimpedance noise
- Phase delay in high frequency range
- Very hard to develop fast and low noise amplifier
An example of circuit...

- Solution is not unique
- Very old topology, but latest technology
- Q1: SiGe:C NPN (8th generation)
- Low noise op-amp for LPF

Ask questions to Akimichi!
A few PEs pulse with New Amplifier

1bin 5mV, 10ns

~20ns

~300ns

1PE ~10mV

No overshoot!
Setup (for room temperature measurements)

IWATSU DS-5534 350MHz/2GS/s

PC

ND Filters

Optronscience, Inc.
FC, SMA connector
(type collimator)

TAMA Electric Inc. LDB-100
407.7nm, Pulse Width 49.3 ps
(operating with 3kHz, internal trigger)
Waveform Data

Fitting Function = pedestal_gauss + signal_gauss + shoulder_exponential

<table>
<thead>
<tr>
<th>ne_3.0kV</th>
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<tbody>
<tr>
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<tr>
<td>2.341e+06</td>
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<tr>
<td>RMS</td>
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<tr>
<td>5.796e+06</td>
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<tr>
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</tr>
<tr>
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<tr>
<td>1e+04</td>
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<tr>
<td>Skewness</td>
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<td>2.495</td>
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</table>
Charge Resolution and Gain

BLUE  Temp. 20C, LV Cont. 1.00V
GREEN Temp. 20C, LV Cont. 1.10V
RED   Temp. 20C, LV Cont. 1.20V

*With 9a-series preamp

charge resolution

1x10^8

5x10^7

preliminary

gain
Timing Resolution

Signal timing: Fixed threshold 5mV

Trigger Timing: Get the down slope and take the timing of half of pulse height

Signal time = Signal timing – Trigger Timing
Timing Resolution

With 12a-series preamp @ room temperature (24°C)

histograms of signal times sliced in charge bins
Timing Resolution

- HV cont. 3.0V, LV cont. 1.2V
- Late pulses are currently investigated

In FWHM

In gaussian fit sigma

preliminary

preliminary

1 ns

1 ns

mean charge in the bin [nPE]

timing resolution FWHM [ns]

timing sigma (gaussian fitting) [ns]
Dynamic Range (peak voltage)

With 12a-series preamp
@ room temperature (24°C)

Ratio of rms of peak voltage

Laser intensity A.U (ND Filter Attenuation value)

(~1 PE)
Has very strong temperature dependency

These are scaler count measurement. Need to check correlated dark noise.
Summary

- New preamplifiers for Hamamatsu 8-inch Hybrid Photo Detector (R12112) has been developed.
- Charge resolution at typical operation voltages is 10%.
- Timing resolution (FWHM) is 1.1 nsec for one photo-electron signal, could be better with parameter tuning.
- First result of dynamic range for pulse height measurement shows O(3) extent for pre-amplifier only. We continue optimizing main amps and repeat the measurement for charge dynamic range.
- Noise rate and optimum operation voltages strongly depend on operation temperature.
- Next plans:
  - After pulse measurement
  - Correlated noise measurement
Back up
Cf: Hamamatsu Preamplifier

- Time resolution for 1PE: 
  2.1ns ~ 2.4ns

- Not too bad compared with 10 inch Hamamatsu PMT (2ns on average)

- Could be improved by removing noise from ground line

- Very mild temperature dependence, stable at least within -25~35 degrees

<table>
<thead>
<tr>
<th>HPD (Hamamatsu R-12112)</th>
<th>Time Resolution (nsec)</th>
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<tbody>
<tr>
<td></td>
<td>Temperature</td>
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<tr>
<td></td>
<td>HV Cont.</td>
</tr>
<tr>
<td></td>
<td>-36 °C</td>
</tr>
<tr>
<td>2.8 V</td>
<td>2.1</td>
</tr>
<tr>
<td>3.0 V</td>
<td>2.3</td>
</tr>
<tr>
<td>3.2 V</td>
<td>2.1</td>
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</tbody>
</table>

※LV Cont. is fixed at 0.8 V
Maximum LV control value

LVCont. 1.0V (256V)

LVCont. 1.1V (282V)

LVCont. 1.2V (308V)

LVCont. 1.3V (334V)
Developing preamplifier and main amplifier

Preamplifier

Main Amplifier

Power Socket
(5V DC)
Noise Rate at -34.5°C

![Graph showing noise rate vs HV control voltage at -34.5°C.](image)

- **Noise Rate** (Hz) at 10mV threshold
- **HV Control** (V)
- **Noise Rate at -34.5°C**
  - LV Cont. 0.7V
  - LV Cont. 0.8V
  - LV Cont. 0.85V
  - LV Cont. 0.86V
  - LV Cont. 0.87V

**Key Points**
- 500Hz
- 3.15V (8.85kV HV)
Measured with two IceCube DOM main board and Hamamatsu Pico Pulser

- Hamamatsu C8898
- Sync. out
- DOM MB 1
- Coincidence
- DOM MB 2
- Freezer

Signal Out

changed negative signal to positive
The 1st trial (early 2015)

✩ Too much noise (~100kHz) and electric discharge!!

✩ Hamamatsu tried to fix it, but eventually they send us a replacement. (Because it's hard to fix it once heavy electric discharge happens? We don't know why.)