Signal Processing and Electronic Noise in LZ

2015/08/29
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Topics

● Electronics in LZ
  ○ Focus on Xe space PMTs

● Signal processing
  ○ Noise
  ○ Gain linearity

● Electronic chain test
  ○ Setup
  ○ Goals
LZ Detector Overview

120 outer detector PMTs

7 tonne liquid xenon time-projection chamber

488 photomultiplier tubes (PMTs)
Additional 180 xenon “skin” PMTs
Electronics in LZ - I

- Electronics Racks
- Breakout Boxes
- HV Flanges + HV Filter
- Amplifier Cages
Electronics in LZ - II

- 488x R11410 PMTs for Xe TPC
  - High-energy route to Digitizer and Sparsifier
  - Low-energy route to Amplifier

- 180x R8520 PMTs for the Xe skin
- 120x R5912 PMTs for the outer detector

- PMT -> Amplifier -> Digitizer and Sparsifier -> Disk

On behalf of the LZ collaboration

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## Electronics in LZ - Cables

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>Type</th>
<th>Length (ft)</th>
<th>Additional Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal Cables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal/HV from Xe PMTs</td>
<td>Gore 3007</td>
<td>45</td>
<td>low heat load, low background, low signal attenuation</td>
</tr>
<tr>
<td><strong>External Cables (low smoke zero halogen)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Voltage</td>
<td>Kerpen-48 core</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Signal</td>
<td>LMR-100A-FR</td>
<td>56</td>
<td>low signal area attenuation</td>
</tr>
<tr>
<td>Logic</td>
<td>LMR-100A-FR</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Network</td>
<td>Belden 7936A</td>
<td>Varying</td>
<td></td>
</tr>
<tr>
<td>HDMI</td>
<td>TBD</td>
<td>TBD</td>
<td>low signal loss</td>
</tr>
</tbody>
</table>
Pre-prototype tested in Spring ‘14

Xe TPC PMTs amplifiers design specifications:
- Dual gain output
- 4 output channels/ input channel

- High-energy (HE) channel
  - Shaping time (FWTM) of 30 ns
  - Area gain of 0.5
- Low-energy (LE) channel
  - Shaping time (FWTM) of 60 ns
  - Area gain of 20

Design requirement: total front end electronics noise <0.5mV

Pre-prototype designed at UC-Davis
Signal Processing - Test Results

- Performance evaluated with fast and slow pulses:
  - Fast pulses:
    - 10 - 50ns risetime
  - Slow pulses:
    - Gaussian pulses
    - 150 - 1500 ns risetime

- Test Results:
  - Area gain matched specifications
  - Noise within acceptable bounds
  - Could not measure crosstalk (crosstalk < 0.5%)
  - HE shaping is fine. LE shaping needs changes

(Yellow) Input pulse to pre-prototype amplifier: 180mV, 17ns
(Cyan) Low-energy channel
(Pink) High-energy channel
● New Xe TPC PMTs amplifiers design specifications:
  ○ 2 outputs/input channel
  ○ 8 input channels/board
  ○ High-energy (HE) channel
    • Shaping time (FWTM) of 30 ns
    • Area gain of 4
  ○ Low-energy (LE) channel
    • Shaping time (FWTM) of 60 ns
    • Area gain of 40
● Shaping time now matches specifications
● New design to be tested in Fall ‘15
Signal Processing - Digitizer

- Digitizer design specifications:
  - 32 input channels/board
  - 100 MHz sampling frequency
  - 14 bit resolution
  - 2 V dynamic range

- Total front end electronic noise (RMS):
  - DDC32: $1.19 \pm 0.02$ ADCC
  - HE + DDC32: $1.22 \pm 0.02$ ADCC
  - LE + DDC32: $1.58 \pm 0.02$ ADCC
  - $<0.5$ mV (4 ADCC) noise per channel

DDC32 daughter card designed by SkuTek.com

Noise Waveform

![Noise Waveform](image-url)
Averaged Fourier transforms of noise waveforms

- Noise falls as $1/\sqrt{\text{Hz}}$
- No predominant noise components

![Graph showing spectral power vs. frequency for different channel combinations: (Black) DDC32, (Red) DDC32 + LE channel, (Blue) DDC32 + HE channel.](graph.png)
Signal Processing - Gain Linearity

- Measured high-energy channel area gain of 0.5
- Measure low-energy channel area gain of 20
- The digitizer saturates at 1.8V and the amplifier saturates at 2.6V
- Developing methods to recover from saturation
- Below are plots of gain linearity for 20ns fast pulses; errors <1%

![High-energy channel output area vs input area](image1)

![Low-energy channel output area vs input area](image2)
Electronic Chain Test - Setup
Build a test setup to include:
- The full LZ electronics chain from PMT to disk on the event builder
- LZ Xe TPC PMTs and base
- Signal and HV flanges
- Connectors and cables with lengths to be used in LZ
- Hardware, software and firmware that will be used in LZ

The purpose of the setup is to provide a development system to:
- Extensively test hardware, software and firmware before deployment in LZ
- Test every component in the chain
- Obtain real measurements of performance
Electronics Chain Test - Goals

- We will stress test this chain and their individual components

- Having two full digitizer and sparsification chains allows us to:
  - Demonstrate how different sparsifiers can work in different modes
  - Evaluate the DAQ master computer and Run Control’s ability to monitor and control the setup
  - To see how the event builder handles building events from multiple disks

- With LEDs we will:
  - Generate small and large pulses to study the effect of saturation in the all the components of the chain
  - Generate high pulse rates to stress test the acquisition system
  - Develop techniques to perform PMT timing calibration

- Study what happens when the PMT base saturates

- Study the noise of the full electronics chain

- Develop techniques to eliminate common mode noise
Thank you

2015/08/29
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## Electronics - Cable Attenuation

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>Length (ft)</th>
<th>Tested Pulse</th>
<th>Area Attenuation (%)</th>
<th>Amplitude Attenuation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gore 3007</td>
<td>45</td>
<td>2-ns risetime</td>
<td>-18</td>
<td>-56</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>&quot;</td>
<td>-28</td>
<td>-80</td>
</tr>
<tr>
<td>LMR-100A-FR</td>
<td>28</td>
<td>&quot;</td>
<td>-1</td>
<td>-15</td>
</tr>
</tbody>
</table>
Signal Processing - Test Results

- PDDC 32 saturates at ~2V
- Pre-Prototype Amplifier saturates at 2.6V
- Studying methods to reconstruct pulse area up to 2x saturation voltage within an error of <10%

(Yellow) Input pulse to pre-prototype amplifier: 400mV, 17ns
(Cyan) Low-energy channel
(Pink) High-energy channel
Signal Processing - Noise in LUX

![Graph showing noise in LUX signal processing](image)
Electronics Chain Test - Timeline

- Summer ‘15 - Develop Run Control, Event Building, Data Acquisition software and DDC32 Acquisition/Sparsification firmware.

- Sept ‘15 - Deploy code at the machines at the University of Rochester
- Sept ‘15 - Assemble test setup and simulate data with an arb. waveform generator

- Oct ‘15 - Test Run Control, Event Building and Data Acquisition software

- Nov ‘15 - Test gain and shaping for various types of simulated pulses
- Nov ‘15 - Receive two R11410 PMTs to integrate into setup
- Nov ‘15 - Integrate the LED strobe into the setup
- Nov ‘15 - Perform PMT saturation study

- Winter ‘15–’16 - Complete first phase of the electronics chain test