Design and Performance of the VMM1 ASIC for Micropattern Gas Detectors
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VMM1 ASIC
Designed for ATLAS New Small Wheel Upgrade

- Micromegas (MM) Detectors: μ-Time Projection Chamber (TPC) mode (trigger mode)
- Thin Gap Chambers (TGC): trigger mode (μ-TPC mode)
  - Requires precision time (2 ns) and amplitude (2%) measurements and fast read-out for trigger applications
- suitable for other gaseous detectors such as Gas Electron Multiplier (GEM) Detectors
- flexible design that allows it to be tuned to optimize for a range of micro-pattern gaseous detector technologies
  - selectable gain and peaking time
VMM1 ASIC
- Designed at Brookhaven National Laboratory
- 130 nm CMOS
- 64 channels each with
  - Charge Amplifier (CA)
  - Shaper with baseline stabilizer (SA)
  - Discriminator with trimmer (DSC)
  - Peak- and Time-Detector (PD/TD)
  - Time-to-Amplitude converter (TAC)
  - Time-over-Threshold (TOT)
  - multiplexing with smart token
  - Address in Real Time (ART)
VMM1 Features

- **Selectable Gain**
  0.5, 1, 3, and 9 mV/fC
- **Selectable Peaking Time**
  25 ns, 50 ns, 100 ns, and 200 ns
- **Adjustable TAC slope**
  125 ns/V, 250 ns/V, 500 ns/V and 1μs/V
- **Timing Mode**
  Time-over-Threshold (ToT) and Time-to-Peak (TtP) for 16 channels
- **Smart Token Passing**
- **Fast Trigger Readout**
  The Address in Real Time (ART) reads out the address of the first channel with a signal hit
- **Threshold Trimming**
  15 mV trim
- **Sub-Hysteresis**
  automatically adjusts the threshold level before and after peak detection
- **Neighbor Readout**
  reads out channels adjacent to signal channel
Peak Detector

- High precision peak detection (PDO) on each channel
- Variable gain setting of 0.5, 1, 3, and 9 mV/fC
- Internal pulser for test measurements
  - Compare the internal pulser (blue points) to an accurate external pulser (green points) for reliability of gain and baseline measurements for charge signal amplitude and PDO (PDO includes baseline)

Internal Pulser, Gain Linearity

Gain Linearity: g=1mv/fC, pT=50ns
Peak Detector

Resolution:
PDO rms is 0.26 mV
Better than 1% accuracy
• gain = 0.5 mV/fC
• peaking time = 25 ns
• input signal of 248 fC

Linearity:
Percentage linearity error or residual percentage is of the order of less than 1% over full range
• external pulser
• Gain = 1 mV/fC
• peaking time = 50 ns

Input capacitance ~10 pF
Peaking time 50 ns
Gain 1 mV/fC
Time Detector

- Variable peaking time
  - 25, 50, 100, and 200 ns
- The time is measured by charging a capacitor at a specific rate given by the Time-Amplitude-Conversion (TAC) slope
- Variable TAC slope
  - 125 ns/V, 250 ns/V, 500 ns/V and 1μs/V

Resolution:
TDO rms is 0.04 ns
- gain = 0.5 mV/fC
- peaking time = 25 ns
- TAC = 125 ns/V
Time Walk

- ~1 ns variation
- Gain = 1 mV/fC
- Peaking time = 25 ns

=> Timing resolution well within target limit of 2 ns independent of amplitude size for peak detection
Time-Over-Threshold

TOT/TTP Timing Outputs (TGCs)
- 16 channels with:
  - Time-over-Threshold (ToT)
  - Threshold-to-Peak (TtP)

![Graph showing Time-Over-Threshold (ToT) and Threshold-to-Peak (TtP) with parameters: Peaktime 200ns, Input charge 55fC, Gain 9mV/fC.](image)
Other features:

**Adjustable TAC slope** The time-amplitude-conversion (TAC) slope can be adjusted according to 125 ns/V, 250 ns/V, 500 ns/V and 1μs/V.

**Smart Token Passing** This feature allows only the signals above threshold to be read out reducing bandwidth requirements.

**Fast Trigger Readout** The Address in Real Time (ART) reads out the address of the first channel with a signal hit for fast trigger applications.
Threshold

- The threshold inherently has some channel-to-channel variation.
- A threshold trim was included in the VMM1 design to equalize thresholds by allowing each individual channel to be trimmed by approximately 0-15 mV.
Threshold Calibration

• A Fermi-Dirac function was fit to a turn-on curve to extract the mid-point as threshold for each channel
• Threshold measurements were repeated for the minimum and maximum trim settings (green lines represent the range of possible trimmed thresholds)
• A target value was selected closest to the average threshold (red points)
• Channels trims were set at target and measured (blue points)
• VMM2 will allow better equalization by decreasing the spread in threshold by a factor of 4
Sub-hysteresis

The fast comparator introduces a hysteresis, which effectively raises the minimum threshold by approximately ±10mV (i.e. a 20 mV window around the nominal threshold). The sub-hysteresis function was introduced to compensate for this effect by moving the threshold level so that it triggers close to the baseline and resets after the peak is detected.

With the sub-hysteresis function off the lowest effective threshold is here where the circuit can still reset.

Sub-Hysteresis Off  Sub-Hysteresis On

~10 mV
Sub-Hysteresis Performance

Sub-hysteresis
- Sub-hysteresis function OFF (blue)
- Sub-hysteresis function ON (red)

![Graph showing input charge vs signal amplitude with threshold limits]

The PDO is able to read out input amplitudes 56 fC smaller than without for gain = 0.5 mV/fC, peaking time = 25 ns, and injection capacitance equal to 2.44 pF. The measurements show that for these conditions the VMM1 can measure signal amplitudes 11 mV smaller with the Sub-Hysteresis feature than without.
**Fe\textsuperscript{55} Measurements**

**Fe\textsuperscript{55} Source Measurements**
- Micromegas chamber (T6)
- Single plane of strips
- Drift gap voltage = 530 V
- Gas mixture Ar(93%)+CO2(7%)

**Neighbor Channel**
- The Neighbors function allows the read-out of channels below threshold adjacent to any channel above threshold
  - Propagated to neighboring chip

The total charge collected is higher due to the higher strip multiplicity with the Neighbor readout, while the width remains the same for better energy resolution.
Summary

- Successful ASIC design for use with micropattern gas detectors
- The charge resolution was 0.26 mV at a nominal gain = 0.5 mV/fC
- The timing resolution was less than 50 ps for a peaking time = 25 ns and TAC = 125 ns/V
- The linearity error of the gain response was less than 1%
- The Sub-Hysteresis feature enabled the VMM1 to measure signals more than 2 times smaller than without the Sub-Hysteresis
- Neighbor function improved the energy resolution
New Features:

- 6 bit peak detector and digitizer (PDAD) for direct timing
- 10 bit 5 MS/s ADCs per channel and FIFO
  - Fully digital IOs
  - De-randomization
  - Simultaneous measurement and readout
- External trigger
- Counter
- Fix known issues
Backup
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