MASE: Multiplexed Analog Shaped Electronics

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Outline

1. Needs
2. Problems with existing Technology
3. Design Specifications
4. Overview of the MASE system
5. Details
6. Performance characteristics of a channel board
7. USB control
8. Initial results

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Resonant decay spectroscopy of weakly bound nuclei is presently a topic of significant interest. To study such decays requires the ability to resolve multi-particle decays with good angular resolution (high segmentation), as well as good energy resolution.

Examples of such arrays are FIRST, LASSA, HiRA, MUST and MUST II.

Such arrays typically consist of several hundred to a few thousand independent segments. Despite the high segmentation, the number of particles in a given event is small suggesting signals from the independent segments can be multiplexed to a single ADC. As a result the readout of the detector array is both considerably faster and simpler.

Needs -
1. Si Thicknesses from 65 μm-1.5 mm
2. Dynamic range 10 MeV - 8 GeV
3. Capacitance: 20 pF - 400 pF
Challenge: Dynamic range/triggering

- Simultaneous detection of beam-like fragment (Z~50; E/A=50-80 MeV) and a light charged particle (viz. alpha) at forward angles.
- Heavy particle ➔ low gain CSA (0.9 mV/MeV) and shaper
- High energy Alpha particle ➔ Low energy deposit in Si detector. Can we trigger on it?
Timeline

- Idea for MASE developed late Oct. 2004
- Nov. 2004 Preliminary design work begun
- Jan.-Mar. 2005 prototype of shaper, peak-find, track and hold breadboarded
- Mar.–June 2005 concept of master-slave FPGA operation tested with Digilent prototype boards
- Apr. 2005 schematic of channel board developed
- Summer 2005 USB slow control implemented (REU project)
- Nov. 2005 prototype channel boards received
- Feb. 2006 production run of channelboards
- Feb 2006 Design of controller boards and backplane started.
Limitations of the conventional approach

- Not multiplexed \(\Rightarrow\) requires 1 ADC/channel
- Triggering on small signals is limited by the short integration time of the TFA
- CAMAC (a dying standard)
- Larger number of channels \(\Rightarrow\) more channels for redundancy
- Eliminate differences in differential non-linearity between different ADCs
- Scalability is poor (both in complexity and cost)
  - Typical cost of 16-channel shaper (e.g. Picosystems > $3k)
  - Typical cost of 16-channel disc. (> $3k)
  - Typical cost of 16-channel peak-sensing ADC (> $4k)
Goal

Design and build a high-resolution, low-cost scalable system for processing the energy signals of an array that is < 1024 channels.

The basic MASE concept
Design Specifications

- 16 channels/module with dual H/L gain on each channel
- Gain matching of channels to ~1% independent of gain (volume control)
- Time-to-voltage converter (TVC) on each channel to provide random rejection
- 32 independent discriminators on slow signal
- Ability to mask off discriminators
- Easy control of disc. and amplifier gains via USB (independent of DAQ)
- Dynamically controllable polarity of input signal
- Standalone operation of a single module
- Compact crate configuration for a set of 16 modules
- Multi-crate functionality
- Identical DAQ software for single module/crate operation (seamlessly scalable)
- Module addresses are configurable
- Shaping time: 1 μs (Si); 3 μs (CsI(Tl))
- High gain/Low gain = 120; can be reduced
- Dynamic range
  - 10 MeV full scale (with 40 mV/MeV CSA) on low gain
  - 7.5 GeV full scale (with 0.9 mV/MeV CSA)
- Ability to use full dynamic range of ADC (+/- 1V) by offsetting MASE output.
**MASE realized**

**Analog Inputs:**
16 channels from CSA to 34 pin connector on front panel

**Analog outputs:**
Differential Energy and Time streams multiplexed via 2pin LEMO on front panel

**Logical outputs**
Addresses: via LVDS at back of module
Inspect, sum out, fast Trigger, etc via front panel LEMO

**Booting FPGAs:** JTAG interface

**Slow control:** USB

A module is 0.8 in. thick.
• A Channel board measures 16 in. x 9 in.
• Logical decisions are made by a Xilinx Spartan 3 400 and 200 that operate in a master-slave relationship
Overview of the MASE system

16 channelboards/crate + 1 controller
Function block diagram of a single analog channel in the CB
Function Block diagram of CB
Output analog data stream

Multiplexer settling time ~250-300 ns; estimated time/channel ~500 ns ➞ 7 samples at 40 MHz
Readout with XLMXVV (or SIS 3301)

**XLMXVV (JTech)**

- 40 or 65 MHz sampling VME ADC
- 2 dual ADCs per module
- ADC is either 12 or 14 bit
- ADC is +/- 1V full scale
- Logical inputs/outputs via LVDS and ECL (configurable).

**SIS 3301 + XLM80 (JTech)**

- 65/80/105 MHz sampling VME ADC
- 8 ADCs per module (or 4 stripped)
- ADC is 14 bit
- ADC is +/- 1V full scale
XLMXVV (or SIS 3301)
USB control (+ isolation)
MASE high gain shaper shows good linearity to ~0.05% level.
Low gain shaper has non-linearity of <0.1%
Goal of TVC is to allow separation of beam bursts for random coincidence rejection.

- TVC is started by peak-find logical pulse relative to a common pulse.
- can be run in either common stop of common start mode.
• TVC exhibits a dependence on the DAC gain setting (expected from design).

• Calibration of the walk when gains are changed allows the TVC to be used for its intended purpose (random rejection).
Cross-Talk tests

Ortec Pulser

Pre-amplifiers
50 Ω Output Impedence

Test Input

Channel Tested

50 Ω

Output to Digital Scope
1. Input signal is set to be the maximum non-saturating amplitude of the low gain channel.
2. X axis is the fine gain of the induced channel.
3. Y axis is the amplitude of the induced signal in mV.
4. Trend for a fixed Vin shows that x-talk occurs before some amplification, not just on output stage.
5. The observed cross-talk is a maximum of 1 part in 2000.
6. The dominant x-talk is nearest neighbor; next nearest neighbor is completely negligible.
On an absolute scale when the pulsed channel and the induced channel are set to comparable gains, the x-talk is at a level of 1 part in $10^5$. 

Cross-Talk tests

- Pulse: 7 and 9, Induced signal: 8
  - Low Fine Gain
  - High Fine Gain

- Vin = 6.8 V
- Vin = 5.1 V
- Vin = 3.4 V
- Vin = 1.8 V
• MASE exhibits resolution of 30 keV for a 5.4 MeV α, comparable to the conventional PICOSYSTEMS + peak sensing ADC.

• test setup : LASSA 500 μm detector; $^{241}$Am source
Result: Dynamic range/triggering

- With 0.9 mV/MeV CSA (for T1), we have a dynamic range of 7.5 GeV on the low gain shapers of MASE.
- The high gain shapers at a fine gain DAC setting of 160 (with the same CSA) have a full scale of 55 MeV.
- On the high gain we trigger at 600 keV.

As intended in the design, MASE can simultaneously trigger and identify a heavily-ionizing beam-like fragment and a low energy deposit alpha particle.
Estimated Readout time

- Assuming we multiplex 0.5 μs/signal and the DAQ can handle 1 word/μs, we estimate the readout of 8-10 strips in 30 μs.
- ADC digitization occurs in 7 cycles x 25 ns/cycle = 175 ns
- Much of the ADC digitization time can be hidden behind the analog switching.
Features of MASE

- Inspect any channel (both analog and discriminator) in the system (w/o unplugging cables)
- Sum out (50 mV/hit) provides multiplicity information
- Controller board has memory to preserve all settings
- FPGA code can be stored on the channelboard
We have developed a multiplexed analog system for convenient and low-cost readout of detector arrays (e.g. Si) of < 1024 channels.

Resolution of <30 keV for a 5.4 MeV alpha particle has been achieved.

Linearity, Cross-talk, etc. are well within acceptable limits.

The channelboard is now in production stage

The controller and backplane are presently in the design stage.

We estimate completion of the project by summer 2006.