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GlueX Electronics Status and Plan

GlueX Electronics Group

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Abstract

This note summarizes the current state of the GlueX electronics systems, and describes the R&D required to fully specify the design. Institutional responsibilities are noted, and manpower needs are addressed.

Summary of GlueX Detector Subsystems

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Detector	Photon tagger	Pair polarimeter	Pair spectrometer	Upstream Photon veto	Start counter	Central drift	Forward drifts	DIRC	Time-of-flight	Barrel calorimeter	Forward calorimeter
Type	Scintillator	Si microstrip	Scintillator	Scintillator	Scintillator	Straw tube	Planar chamber	Quartz	Scintillator	Sci fibers	Lead glass
Channel count	144 fixed 120 movable	2048	32	112	40	3240	2,856 anode 11,424 cathode	2000 TDC 32 FADC	168	1920 inner 960 outer	2500
Signal source	fixed - PMT movable - SiPM	Silicon microstrip	PMT	PMT	PMT	Straw tube	anode wires cathode strips	Multi-anode PMT	PMT	SiPM	PMT
Physics signal	100 pe	22000 e	100 pe	100 pe	100 pe	338 e	94 e	8 pe	500 pe	250 pe/GeV	250 pe/GeV.
Energy resolution	0.1% (segmentation)	N/A	N/A	10%/√E	N/A	15%	15%	N/A.	N/A	2% + 5%/√E	3.6% + 7.3%/√E
Single channel time resolution	100 ps	10 ns	1 ns	1 ns	350 ps	2 ns	2 ns	200 ps	140 ps	150 + 50/√E ps	400 ps
Gain in detector	10^6	1	10^6	10^6	10^6	2×10^4	10^5	10^6	10^6	8×10^5	8×10^5
Typical charge	16 pC	3.5 fC	16 pC	16 pC	16 pC	1 pC	1.5 pC anodes 0.3 pC cathodes	1 pC	80 pC	32 pC/GeV	32 pC/GeV
Signal range	5	10	10	100	10	3 pC max 100 fC min	anodes: 0.3 pC → 3 pC cathodes: 10 fC → 1 pC	10	10	160 pC max 1.6 pC min 0.16 pC lsb	160 pC max 1.6 pC min 0.16 pC lsb
Preamp gain	no	10^4	no	no	no	250	250	40	no	no	no
Maximum single channel rate	5 MHz	1 MHz	1 MHz	1 MHz	10 MHz	600 KHz	140 KHz	250 KHz	6 MHz	1.4 MHz	2 MHz
Discrimination	constant fraction	no	no	no	constant fraction	no	no	yes	constant fraction	yes	no
Scaler	yes	no	no	no	yes	no	no	no	no	no	no
FADC	8 bits 250 Msps	buffered latch	8 bits 250 Msps	8 bits 250 Msps	8 bits 250 Msps	12 bits 100 Msps	12 bits 100 Msps	8 bits 250 Msps	8 bits 250 Msps	8 bits 250 Msps 0.5 V fs	8 bits 250 Msps 0.5 V fs
TDC	62 ps	special low rate runs only	no	no	62 ps	no	no	125 ps	62 ps	62 ps	no
Level 1 trigger	yes (low rate runs)	no	special low rate runs	no	track count	no	no	no	track count	energy sum	energy sum

1 Introduction

The pipelined electronics for the GlueX detector requires approximately 6,000 "fast" ADC channels, 17,500 chamber preamplifier and "slow" ADC channels, and 3,400 TDC channels. There are currently no suitable commercially available options. Clocking, synchronization, discrimination, and trigger electronics will also be required. The plan is for the GlueX collaboration and Jefferson Lab to design suitable boards based on commercially available components. The chamber preamplifiers will be based on a modification of the ASD series of chips developed for the ATLAS experiment.

Some detector parameters need to be specified more completely than what is in the current design report. A suitable TDC design exists at Jefferson Lab; this may need slight modifications for GlueX. There will be 2 types of ADCs. A "fast" (250 Msps) flash ADC will provide charge and timing information for the channels instrumented with photomultipliers, while a "slow" (100 Msps?) flash ADC will digitize the tracking chamber signals.

2 Detector issues

2.1 Photon Tagger

The photon tagger design is based on scintillator, photomultipliers, and silicon photomultipliers. The JLab TDC in high resolution mode will provide timing measurements. 8 bit, 250 Msps ADCs will provide a charge measurement. Scalers are also required. The silicon photomultipliers may need some electronics designed to supply power to them.

2.2 Beam Instrumentation

This includes a 2000 channel silicon strip pair spectrometer, a 32 channel scintillator hodoscope polarimeter, a small calorimeter, and an active collimator. Preamps and a readout system will be required for the silicon strips. A similar system in Hall B uses a analog multiplexer and a slow ADC to read it out. Buffered latches are another possibility. Special low rate runs will relax the event rate and timing resolution requirements compared to other GlueX detectors. The scintillator based polarimeter and lead-glass calorimeter will use photomultipliers read by the "fast" ADC.

2.3 Upstream Photon Veto

The 8 bit, 250 Msps ADCs will provide charge and time information for this scintillator and photomultiplier based detector.

2.4 Start Counter

Constant fraction discriminators, high resolution TDCs and 8 bit, 250 Msps ADCs will instrument this scintillator and photomultiplier based detector. A track count may be useful in the level 1 trigger decision.

2.5 Central Drift Chamber

Intended to provide tracking as well as dE/dx, it consists of 3240 1.6 cm diameter, 2 m long straw drift tubes read by the "slow" ADCs. Further measurements and simulations will be required to finalize the preamplifier specifications and ADC bit depth and sampling rate. Algorithms for reducing the raw ADC samples into time and charge parameters need to be developed.

A full length prototype chamber exists at Carnegie Mellon University. Studies have begun to determine the optimal gas mixture. The chamber gain has been measured. Preamplifiers originally designed for the JLab CLAS detector will be used to provide signals for tests with TDCs and ADCs. It is important to collect data with a commercial flash ADC in order to determine the minimum sampling rate required. Since there is currently no way to apply a magnetic field to the prototype chamber, simulations will be used to model the electron drift trajectories.

2.6 Forward Drift Chambers

This detector consist of 4 packages each having 6 layers of planar drift chambers. It has the largest channel count of any GlueX detector. A small prototype exists and measurements have begun. The present design report calls for TDC readout of the anodes, and ADC readout of the cathodes. The October 2004 detector review recommended considering the use of dE/dx information from these chambers to help with particle ID. Commonality with the CDC electronics is also desirable. For these reasons, current thinking is to use the same preamplifiers and slow ADCs as the Central Drift Chamber on both the cathodes and anodes of the Forward Drift Chambers.

It is important to collect data with a commercial flash ADC in order to determine the sampling rate and bit depth requirements. It may be possible to apply a magnetic field to the small prototype chamber. Simulations can also be used to model the electron drift trajectories. Algorithms for reducing the raw ADC samples to time and charge need further development. A test run is planned to test the dE/dx capability.

2.7 Cerenkov

A quartz DIRC is being considered which would require 2000 PMT channels. The design is a modification of a similar detector used in BABAR. TDCs with 125 ps resolution are specified along with ADCs to monitor the PMT gains. A preamp with a gain of 40 will be required. An existing SLAC design for the preamp will need to be modified since the chips used are longer being manufactured.

2.8 Time-of-flight

Consisting of scintillator bars viewed by fast PMTs, this detector design is fairly advanced. There have been several beam tests and NIM publications. The electronics consists of discriminators, 60 ps resolution TDCs, and 250 Msps ADCs. The only major decision remaining is whether to use constant-fraction or leading-edge discriminators. The ADCs will monitor the photodector gains and may be used to provide a time-walk correction to the TDC information, and possibly dE/dx information. A track count from this detector will be used in the level 1 trigger decision.

2.9 Barrel Calorimeter

The design of this detector follows closely the design of the KLOE barrel calorimeter. A 4-m module exists and will be tested in Hall B in 2006. A second 4-m module is under construction. The choice of photodector is the subject of continued R&D, but is likely to be silicon PMs, a new but promising technology immune to the large fringe fields from the GlueX solenoid. This detector also provides Time-of-flight information for charged tracks. Currently, the design report has discriminators and TDCs to provide timing information and 8 bit, 250 Msps ADCs to provide the energy measurement. An energy sum from this detector is used in the level 1 trigger. Simulations to optimize the detector segmentation and ADC/TDC channel counts are ongoing.

2.10 Forward Calorimeter

This lead glass calorimeter is based on the design of the electromagnetic calorimeter used in Brookhaven experiment E852 and uses the lead glass, phototubes and signal cables from that 3000-element detector. Experience gained with using a smaller version of that detector (784 elements) in a photon beam in the Radphi experiment suggests that resolution improvements can be made by using light guides (instead of an air gap) between the glass and phototubes. A 64-element calorimeter, with improved light coupling, will be tested in Hall B in 2007. Low power bases for the FEU84-3 PMT have been prototyped, but work remains to understand how to best mass produce them. Indiana University is responsible for these bases. The readout electronics is 8 bit, 250 Msps ADCs. An energy sum from this detector is used in the level 1 trigger. Silicon photomultipliers are an attractive option for the photodetectors due their magnetic field immunity and relatively low bias voltage needs.

3 Electronics issues

3.1 Preamplifiers and Discriminators

Detector mounted preamplifiers will be required for the Central and Forward drift chambers. The prototype chambers are currently instrumented with JLab CLAS preamps. The chamber preamplifiers should be charge sensitive with differential outputs to drive a twisted pair cable. Low noise with up to 80 pF of capacitance from the longest cathode strips is another important consideration.

The UPenn ASD series of preamps originally developed for ATLAS will be the starting point for a modified chip. EE Students at UPenn will perform the design under the direction of Mitch Newcomer. The University of Alberta has overall responsibility for this project; they will fabricate test boards for the preamps and perform testing. The preamps will be tested with prototype chambers as soon as they are available; currently this is estimated to be in the fall of 2006.

Preamplifiers with a gain of about 40 are needed for the DIRC multi-anode PMTs. A design originally developed at SLAC will be the starting point, but the chips used in it are no longer available. A discriminator will be needed to drive the TDC inputs. One fast ADC channel will monitor each 32 anode PMT. The University of Tennessee is responsible for DIRC electronics.

Discriminators are also needed for the Photon Tagger, Start Counter, Time-of-Flight, and some channels of the BCal detectors. The University of Alberta is responsible for discriminators and has produced a prototype constant-fraction module.

3.2 Silicon Photomultipliers

Silicon Photomultipliers (SiPM) are a promising photodetector technology based on an array of Geiger-mode photodiode pixels. The output signal is the summation of current from the pixels which fired in response to light. These devices have gain and quantum efficiency similar to PMTs, but only require about 50 volts of bias. The current generation of these devices have an active area of 1 mm^2 and will work for the Photon Tagger. Larger devices (1.2 cm^2 active area) are being developed under a contract with SensL [1] for the Barrel Calorimeter. If successful, SiPMs are an attractive option for replacing most of the conventional PMTs in the GlueX experiment.

3.3 TDC

The Jefferson Lab Fast Electronics group has designed and built 100 VME modules based on the University of Freiburg F1 chip which is commercially available through ACAM. [2] This module has 64 channels in its standard resolution (120 ps) mode or 32 channels in high resolution (60 ps) mode. Minor changes may be made in this module for GlueX. The current version of this module is in use in halls A, B, and C at JLab.

3.4 ADCs

The present design assumes 2 types of ADCs:

1) A 16 channel, 8 bit, 250 Msps version for the calorimeters and other photodetectors. The calorimeters also require an integrated energy sum which is used in the level 1 trigger.

2) A 64 channel, 12 bit, 100 Msps version for the tracking chambers.

The Jefferson Lab Fast Electronics group is designing a 16 channel VME module based on the Maxim 112x series of pin-compatible converter chips. These chips provide 8, 10, or 12 bits at 170, 210, or 250 Msps. The energy sum required for the calorimeters will be formed on each card. Partial sums from each card are sent to a crate level sum over a VXS backplane. Clock, trigger, synchronization are also distributed over this backplane. This system is intended for use in the existing JLab experiments as a replacement for aging FASTBUS ADCs as well as for use by GlueX and other new experiments in the existing halls.

The drift chambers don't require a 250 Msps sampling rate, and 8 bits is insufficient. The present design specifies 12 bits at 100 Msps for all chamber planes. Further tests are required to specify what is actually required. An R&D program to further reduce the sampling rates for the chamber ADCs through analog preprocessing (for example a ringing integrator) will be pursued. The Indiana University Cyclotron facility is responsible for the tracking chamber ADC system.

The on-board algorithms for reducing the raw ADC samples into a charge and time measurement need further development, especially for the drift chambers. These algorithms also need to take into account any analog preprocessing.

3.5 Clocking and synchronization

The digitally pipelined electronics proposed for GlueX is assumed to be clocked in synchronization with the accelerator beam time structure. The distribution of the appropriate clock, reset, trigger, test, and monitor signals has been discussed (for example at the December 2004 and April 2006 electronics workshops), but a lot of work remains to be done, and additional manpower is required. Jefferson Lab is responsible for this system.

3.6 Readout Bus

The present bus standard being used for the TDCs and proposed ADCs at Jefferson lab is VME64X. The VXS backplane extension will be used for the next generation of these modules to distribute the sampling clock and other timing signals, as well as to gather the energy sums from the calorimeter ADC modules.

3.7 Trigger

Some GlueX trigger simulations were done in 2002 and are summarized in the design report. The present design specifies a hardware trigger based on calorimeter energy sums and a track count from the forward Time-of-flight detector. However, a lot of work remains to be done on this important aspect of the experiment. Some issues are:

Which detector elements should be included?

How should the trigger be partitioned between hardware (Level 1) and software (Level 3)?

Is there a plausible need for a level 2 trigger?

What background processes are the most important to reject?

Is the time estimate for the level 1 trigger of 3 μs realistic?

4 Measurement and Simulation Priorities

There are a number of open questions related to GlueX electronics, especially regarding the tracking chambers:

Are the FDC cathode charge measurements adequate to provide dE/dx information, or is the anode charge required as well? Is adequate drift time resolution available from ADCs on the anodes?

What is the optimum gain and time shaping for the chamber preamplifiers?

What ADC bit depth and sampling time is required for the chambers? Can additional shaping reduce these requirements? What algorithms will be implemented in the ADC hardware?

Much of this work can build on what has already been done by other experiments. [3] [4] [5] [6] [7] [8] [9]

What time resolution is needed for the level 1 trigger calorimeter energy sums?

Can adequate charged particle time-of-flight resolution be derived from the BCal ADCs or are TDCs needed as well? How many ADC and TDC channels are optimum for the BCal?

5 Responsibilities, Management, and Milestones

Partitioning of the various aspects of GlueX electronics R&D among participating institutions has essentially been "self-assigned" based on interests and available personnel. This process has worked well, but as GlueX moves from an R&D phase into actual construction institutional responsibilities will need to be formalized. Another important clarification will be the responsibility for long-term maintenance and repair of electronics. The design report describes a management structure, but this needs to be fleshed out. The design report also describes a "Technical Review Committee"; this will need to be implemented in order to review various aspects of the electronics design, especially those for which considerations beyond the strictly technical will influence the decision. Additional internal and external reviews will be required.

Prototype silicon photomultipliers optimized for the Barrel Calorimeter will be provided by SensL as part of phase 1 acceptance tests during the summer of 2006. These will be tested at various collaborating institutions. Further testing will determine the suitability of SiPMs for other GlueX detectors.

Another milestone is a beam test of 64 channels of the lead-glass forward calorimeter in the summer of 2007. For this test Jefferson Lab should provide prototype 250 Msps FADCs and a working energy sum trigger. A clock distribution system phase locked to the accelerator master oscillator must be available as well as a new trigger supervisor module. The Hall B Tagger should be instrumented with JLab F1 TDCs for these tests.

One large milestone is CD3; the plan is to have all designs complete by this time so that construction can begin. A 3 year schedule should be adequate to produce all electronics given adequate funding. Since the electronics is likely to be a critical path item in the GlueX construction schedule, it makes sense to begin as much electronics construction as possible at CD3A.

6 Manpower

At Jefferson Lab, at least one engineer and one senior technician are needed to work with the Fast Electronics and Data Acquisition groups in order to design, test, and support new GlueX electronics. An additional engineer is needed to integrate the detector mounted electronics, especially chamber mounted preamps, and to solve cable routing issues. The GlueX design report specifies that the various sub-detectors can be operated in the extracted position without uncabling; the cables either need sufficient slack, or the electronics needs to move. Preamps inside the GlueX solenoid need to be cooled. There are a number of "slow control" systems in the GlueX detector; for example low and high voltage power supplies, temperature sensors, etc. One additional engineer or senior technician is needed to specify these systems; preferably in a consistent way for all JLab experiments. Commonality of electronics among all 4 experimental halls is extremely desirable to maximize the use of scarce engineering resources. [10]

At the various collaborating institutions, sufficient manpower currently exists to develop designs for detector specific electronics. It will be important to properly phrase long-term agreements between Jefferson Lab and other institutions so that on-going responsibilities for electronics are guaranteed. The lifetime of GlueX is long enough that personnel turnover will occur; institutional support for electronics needs to continue despite this.

References

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