GA–A25822

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This is a preprint of a paper to be presented at the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007, Albuquerque, New Mexico on June 17-21, 2007 and to be published in the *Proceedings.*

Work supported by
the U.S. Department of Energy
under DE-FC02-04ER54698

GENERAL ATOMICS PROJECT 30200
JUNE 2007

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DIII-D CAMAC Infrastructure Maintenance Experience and Upgrade Plans

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Abstract— **Over the past 20+ years the DIII-D project has developed a large CAMAC-based data acquisition and control infrastructure consisting of 9 serial highways, 87 crates and 1258 CAMAC modules in service and about 420 spare modules. The cost and difficulty of maintaining these older systems is continually increasing. The use of alternative hardware for new installations and replenishing CAMAC spares from obsolete systems is underway. Onsite repair and utilization of some vendors that will still repair CAMAC modules is important in our program. Over the past five years we have been implementing new diagnostics and control systems with modern hardware. The current plan is to incrementally replace much of the existing CAMAC infrastructure with new equipment as time, machine availability and budget permit. A functions- and requirements-driven approach to the design will be outlined. Data will be presented on experience with candidate control and DAQ hardware in use at DIII-D. Some success has been realized with new waveform digitizers, thermocouple acquisition and digital I/O. Candidate control hardware will be discussed including PCI/cPCI systems, PLCs, Ethernet direct-connected server systems, and others. The functions, performance and design requirements of replacements for specific CAMAC-based modules and systems in DIII-D will be outlined. Design requirements will emphasize compatibility of interfaces to existing equipment, reliability and maintainability. Ethernet is the preferred medium of connection to the host data acquisition or machine control computer systems.**

Keywords- CAMAC; maintenance; upgrade; pci; digitizer

I. INTRODUCTION

The longevity and versatility of the DIII-D experiment, spanning the years from 1986 to the present, has left us with a great deal of legacy equipment still operating in our data acquisition and machine control systems. Although the acquisition and control computers have been kept up to date, the field hardware, specifically Computer Automated Measurement and Control (CAMAC), has remained in place. CAMAC is defined by the ANSI/IEEE standard 583-1982. CAMAC specifies a bit or byte serial communication path in a ring architecture. CAMAC implements substantial error checking for transactions which is advantageous for troubleshooting but the troubleshooting can be done only when the ring is operative. For the ring to be operative, every crate on the ring (commonly referred to as the highway) must be responding. If not, messages will stop or be garbled at a defective ring node (commonly referred to as a crate), the location of which is often difficult to determine.

Recent additions to data acquisition and control systems have generally been accomplished with modern hardware but budgeting and machine availability considerations have limited the upgrading or replacement of existing CAMAC installations to a small number of locations. The increasing difficulty of servicing and obtaining replacement components has led us to increase focus on our plans to migrate from our installed CAMAC to more current and maintainable technologies.

II. OVERVIEW OF CURRENT SYSTEMS

The DIII-D experiment runs nine major CAMAC highways and some smaller highways dedicated to a single diagnostic experiment. One major highway is for the machine control system, four are on the data acquisition system and four are for neutral beam injection systems.

The control highway is populated with digital I/O, ADCs, DACs, and machine timing system receivers and delay generators. The timing receivers and delay generators, programmed pre-shot, perform the real time functions of power supply sequencing, switch enabling, etc for the shot cycle. Thus no real time requirements are imposed on the highway itself. There are 16 crates on the control highway supporting 3190 discrete and 1327 analog points. The highway is operated by an I86 PCI machine running Linux. The interface between CAMAC and the PCI bus is a Kinetic Systems 2115 PCI fiber optic serial highway driver card. Highway media is mixed fiber optic and copper.

Acquisition highways are basically the same as the control highway in physical implementation. Acquisition was split into four highways and two computers for load sharing, troubleshooting ease and to decrease shot data collection times. Approximately 2160 data points, primarily waveforms, are collected from 49 crates during one tokamak discharge. Most of the acquisition highway CAMAC is involved in waveform acquisition. Thus it is populated with digitizers, programmable gain amplifiers, programmable clocks and the same timing system interfaces used in the control highway.

The neutral beam highways combine control and acquisition functions, using one highway per neutral beam injector (two ion sources per injector). The beam systems have their own timing system for power supply control and data acquisition. Otherwise the same modules are used as in control and acquisition functions elsewhere. Each beam highway supports a few hundred points.

III. MAINTAINING THE SYSTEMS

The concern with our current CAMAC control and data acquisition is the increasing challenge to maintain and replace equipment that is not manufactured or unsupported. We have competent in-house capability for repairing the majority of module types, but the technician time for CAMAC repair is carefully managed against other work. A number of parts, especially old ADC hybrids, are very hard to locate. We have had favorable experience with OEM repairs for some modules from Kinetic Systems and Jorway.

Due to this ongoing repair program and the occasional decommissioning of a CAMAC installation, or purchase of a module, we are building a managed spares inventory. Ongoing critical shortages are crate controllers, fiber u-port adapters, programmable clocks, and digitizers.

Outside of our spares and repair capability, we have some backup capacity of installed unused inputs and outputs. We also have a portable PCI computer with four channels of high speed Gage Applied Inc. CompuScope model 14100C digitizers installed. There is at least one D-TACQ 96 channel cPCI digitizer unused at the current time.

IV. HOW NEW INSTALLATIONS HAVE BEEN DONE

A major step away from CAMAC occurred when we began purchasing cPCI and PCI waveform digitizers from D-TACQ Solutions, Ltd for the DIII-D plasma control system real time computers. These are installed in CPUs interconnected by Myrinet or Ethernet [1].

A similar system was subsequently chosen for the new Internal (I-Coil) data acquisition consisting of 96 channels of cPCI digitizer in a Linux box colocated with the coil power supplies. Ethernet brings data to the acquisition computers post-shot. The I-Coil system reports audio amp interlock/readiness status and small-signal patch panel configuration details to the control computer via Sensoray Co., Inc. 2600 Series Ethernet connected DIO modules.

A new over-current detection and interlock system for the DIII-D field shaping coils also uses the D-TACQ cPCI digitizer connected to the data acquisition computers via Ethernet [2].

We choose to use Ethernet because it is easy for us; it exists everywhere in our physical plant and we have a reasonable expectation that the technologies' reliability, maintainability, and throughput will advance enough to keep pace with our performance requirements. Myrinet, a very high speed solution required in the plasma control system, will be used on an as-needed basis due to its high cost.

In 2006 conversion of all neutral beam injector thermocouples from a CAMAC based system to an Ethernet connected system from Sensoray was completed [3]. In general the installation has worked successfully although there were some early hardware failures partly due to our failure to separate grounds. In addition, we suspect that neutron damage is causing occasional hardware failures that will be ongoing. To mitigate this problem we will move the electronics out of the machine hall and/or use polyborate shielding. This design will be used to replace three CAMAC crates that acquire machine vacuum vessel thermocouples. The neutron issue should not be problematic there as the CAMAC is already located many meters from the DIII-D machine and is behind our shield wall.

Another successful elimination of a single CAMAC crate was performed last year at the interface to the DIII-D vacuum control system. The vacuum control system uses a General Electric programmable controller (PLC) providing an Ethernet interface. After writing a driver to connect our Linux control computer to the GE PLC, we were able to remove this crate and have more vacuum control information available than had been hard wired between the PLC and CAMAC. The crate had also contained a machine timing system receiver that was simply replaced with a stand-alone unit we have been buying from Palomar Scientific Instruments of San Marcos, California [4].

A number of DIII-D diagnostics have been originated with this hardware. Most connect via Ethernet and send data post-shot, but a few directly connect to the plasma control system by Myrinet for real time plasma parameter control.

The waveform digitizers we have been using have been those mentioned above from D-TACQ Solutions, Ltd in the UK. These offer 96 channels in a 1 wide cPCI 6U card for around $10,000. While this is only $100 per channel, to fully realize this price we must use as many channels as possible per card since they all use the same clock and stop trigger. We have many smaller channel count installations and many lower sample rate requirement installations too. We are proposing different solutions for these instances as will be indicated in Table 1 in the following section.

A few PXI systems for data acquisition and control have been deployed in our Fast Wave and ECH heating systems. These have been successful although the per-channel cost of waveform digitizers was found to be higher than those for PCI.

V. OPTIONS FOR UPGRADE HARDWARE

Table 1 indicates the different options we have identified for CAMAC replacement hardware. The choices are based upon whether the selected unit or class of hardware performs the function of the hardware it is replacing and whether it meets our current design and performance requirements. Functions and requirements are shown in the table.

VI. THE UPGRADE STRATEGY

Functions and requirements for each physical site of a system targeted for upgrade will be reviewed. Appropriate hardware will be installed and connected to the interfacing system either with design drawings or interface control documents. Many of these physical locations contain CAMAC systems, which, due to the expense of the technology at the time, serve several nearby field coil power supplies or systems. With today's lower cost of control and data acquisition components, we can afford to be more flexible and will exercise the option of removing a CAMAC crate and distributing its functions to one or many Ethernet connected units with appropriate function(s). Additionally it is possible to piecewise replace functions in a particular crate until the crate is empty and obsolete.

TABLE I. CAMAC REPLACEMENT CANDIDATE HARDWARE ITEMS

Function	Representative Old Unit	Typical New Unit	Cost	Performance Requirements
DAC 8 ch	Kinetic sys 3110	PCI, PXI, PLC, USB, Ethernet device	500	10 bits min, <10 ms setup
ADC 16 ch	LeCroy 2232	PCI, PXI, PLC, USB, Ethernet device	400	12 bits min, <10 ms convert
Digital IO 48 ch	Kinetic sys 3082/4371	PCI, PXI, PLC, USB, Ethernet device	300	200 volt gnd isolation/ch
Slow digitizer 16 ch	LeCroy 8212	PCI, PXI digitizer, PCI/USB ADC streamed to disk	400	dc-10 k S/S, ± 5 V, 12 bits
Fast digitizer 96 ch	LeCroy 2264/TRAQ	PCI, PXI digitizer	10,000	dc-250 k S/S, ±5 V, 12 bits
Thermocouples or sensors 16 ch	Kinetic sys 3525	Ethernet connected device or USB on host	400	0º-500ºC, <50 ms convert
Timing receiver	GA	Stand-alone with appropriate housing	3500	General Atomics Spec.
Delay generator 8 ch	Jorway 224/226	PCI, PXI counter-timer	400	<1 μs resolution
Clock	Jorway 217	PCI, PXI counter-timer	400	<1 μs resolution
Programmable gain ampere 8 ch	Transiac 1008	PCI, PXI PGA	3300	1–128X gain, 1% figures
Crate controller	Kinetic sys 3952	PCI CPU or server SW	2400	Ethernet 100baseT min.

Fig. 1 shows our basic replacement strategy using devices that are Ethernet connected and interface as required to the system the old CAMAC was connected to.

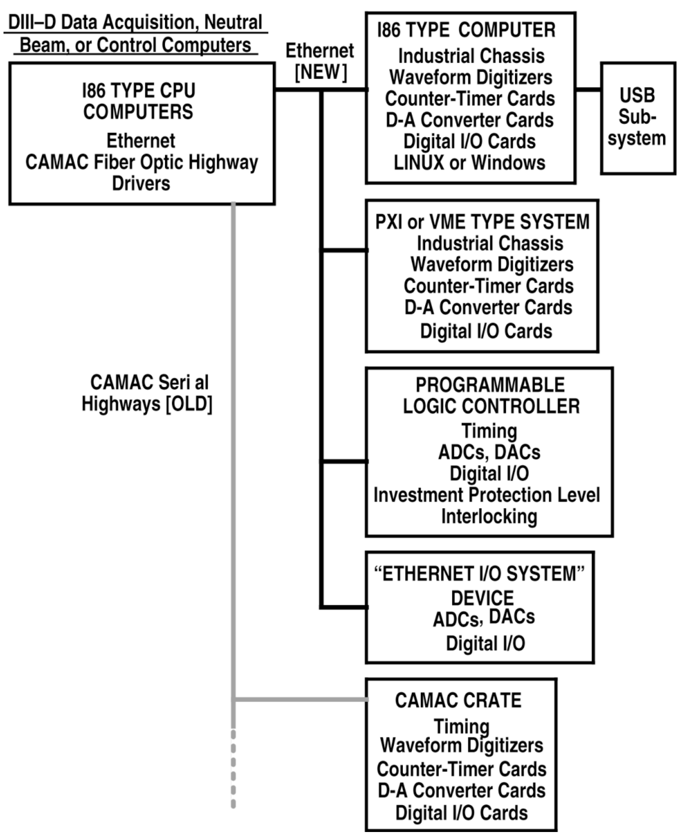

Figure 1. Representative Ethernet connected CAMAC replacement hardware items.

It is proposed that some installations of CAMAC hardware be kept on line while migrating to new hardware. First monitoring functions would be tested, and then a graduated level of control would be turned over to the new hardware as its reliability is shown.

Fig. 2 shows an implementation that could replace the CAMAC crate that controls the field-shaping power supplies (FPS02). This crate is on the control highway and is the control interface to seven of our moderately large DC supplies supplying current for plasma shaping and positioning coils by way of SCR choppers of our design and commercially purchased switched power amplifiers (SPAs). The crate also interfaces to some of the controls for the newer 32kW audio amplifier based coil power system.

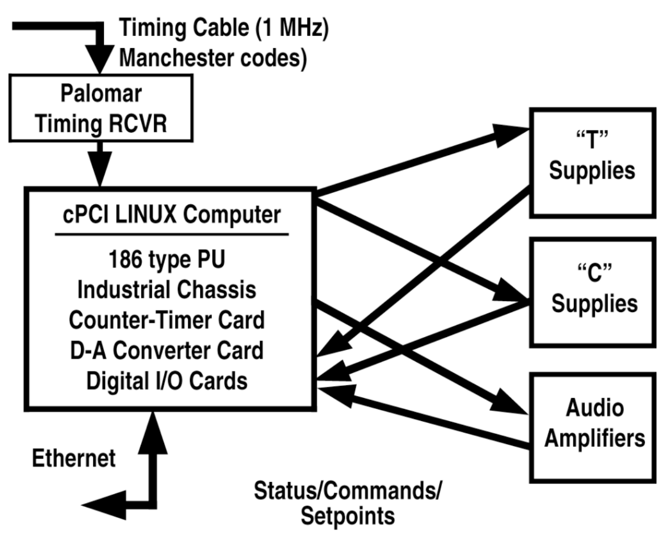

Figure 2. Replacement hardware for FPS02 power supply control CAMAC station.

Crate FPS02 contains the following modules to perform its monitoring and control functions: Timing components including a 4 channel timing receiver, gated clock, and two programmable pulse delay generators. Monitoring and control including 48 digital input points, 48 digital output points, and 16 DACs to preset supply set points and limits.

The replacement for the installation described above would consist of a PCI computer in an industrial box. It would contain a PCI counter-timer board with at least 8 channels to provide the clock and delay generator functions. The timing receiver function would be implemented with a stand-alone receiver.

The DAC and digital I/O functions are easily provided with any number of COTS products, including those with voltage and ground loop isolation, self-verification, and load testing. If desired we will include an ADC for set point and limit verification before the shot fires, adding inexpensive additional protection for coil supplies.

An alternate design solution to the FPS02 replacement would utilize a programmable controller to replace the DAC, ADC and DIO functions. This gives some advantage, providing local intelligence for redundancy and diversity of setup error checking. In some cases, subject to review, it should be possible to use the programmable controller to perform the real time supply sequencing, eliminating the need for the PCI box. Programmable controllers that implement real time properties such as ladder segment scheduling and task preemption could be selected.

Another illustrative installation is a typical neutral beam CAMAC system in the power supply area. The system sequences the power supplies and records supply waveforms and status. The proposed replacement plan is to use Ethernet connected digital I/O for non-real time control and status reporting. These include loading and verifying supply set points, enabling supplies, verifying status of interlocks, and closing breakers or contactors. Waveforms would be recorded by the previously discussed cPCI digitizer hosted by an I86 based Linux processor. The real time sequencing of the beam power supplies would be done by the existing triggers as is currently done. The proposed arrangement is shown in Fig. 3.

VII. CONCLUSION

At DIII-D we are moving forward with replacing CAMAC data acquisition and control components that present availability and investment risk to the project. The replacement systems will interface to control and data acquisition systems by Ethernet and will be selected according to the interfacing systems' requirements and environment. Replacement systems have included cPCI, PCI, and PXI, Ethernet connected devices, and programmable controllers. The cPCI and PCI computers will run LINUX or Windows and will host waveform digitizers, ADCs, DACs, DIO, USB devices and counter-timer boards.

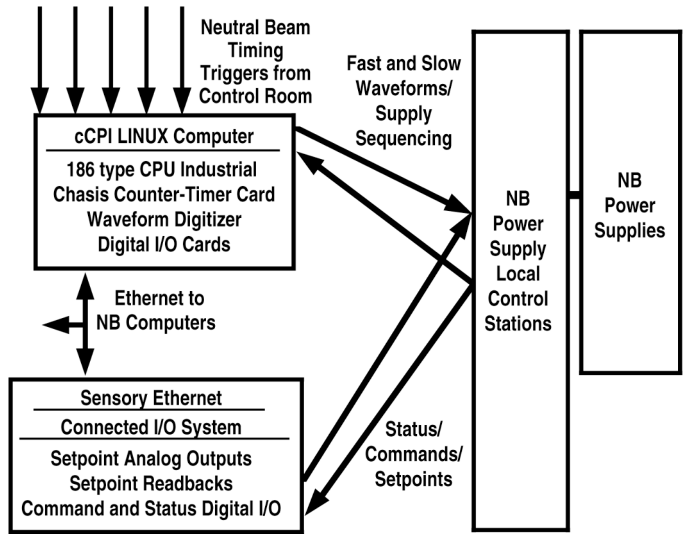

Figure 3. Replacement hardware for the neutral beam power supply control CAMAC.

Our success with the hardware that we are proposing to start the replacement program with has validated the design approach.

ACKNOWLEDGMENT

This work supported by the U.S. Department of Energy under DE-FC02-04ER54698.

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