TECHNICAL DEVELOPMENTS

PROGRESS ON THE DATA ACQUISITION SYSTEM SOFTWARE

R. Fox, A Vander Molen, R. Au

The past year has seen the construction of a framework data acquisition system. In addition, several important utility programs have been implemented for the data acquisition system. We report on the construction of the framework data acquisition system, and in particular on the data routing program which is at the heart of the system.

I. Introduction

In a previously published article[1], we established the design goals and requirements for the data acquisition system as we intended to implement it at the National Superconducting Cyclotron Laboratory (NSCL). In designing the software for this system, the most important of these requirements were:

1. To be able to store the acquired data in a manner which is as compatible as possible with the equipment available to outside users.
2. The system should be able to accept, with minimal changes, codes developed by outside users.
3. The system should be easily tailorable to meet a wide variety of experimental needs. In addition several other design goals have been added in the course of building the software.
4. The software must be able to adapt to hardware changes in a manner transparent to user written code.
5. The bulk of the experiments should be able to acquire data with no user programming, while the remainder should only need to code those sections unanticipated by the "normal" system.
6. System written components should be well protected from user written components.
7. System written components should be easily replaceable by user written components (see 2).
8. It should be possible to modify the on line analysis segments without interrupting the flow of data to event recording devices.
9. System written components should only execute in unprivileged processor modes using only well documented operating system features.
10. Overhead of the system written components should be as small as possible.

In the sections that follow, we analyze the implications of these requirements, explain the underlying design and implementation of the software discuss the user interface and give performance information for the system. We indicate the work which must still be done to complete the system (defined as meet all goals above). Finally we present conclusions derived from experience in running the segments of the system currently implemented.

II. Implications of Design Goals

Items 1-4 imply that the software must be written with a very modular structure. Hooks must be provided on which user applications can be hung. Since we serve an outside user community, it would be nice to allow even something as basic as the tape structure to be user modifiable in the event an outside user wished to write tapes in a format which would directly match some analysis program run at the home institute.

The protection requirement (item 6) and the run time modifiability requirement (item 8) imply a modularity beyond that of a single program. Thus, some sort of multitasking system was decided on early in the game, each task performing only a relatively limited set of operations on the data or a sample of the data. This implies in turn some method of distributing data or copies of data to tasks both user written and system supplied.

There is really only one way to route data to multiple processes without incurring large overheads. This involves all processes sharing raw data buffers on a read only basis.

III. Implementation of the System

At NSCL, data is initially acquired from CAMAC digitizers by a front end computer of some sort. For the purposes of this discussion, it is unimportant whether the front end be the original LSI-11 system, the new 68000 system described elswhere[2,3], or even the FALCON based magnet mapper data acqusition system[4]. The front end processor collects data into 8kbyte buffers. These buffers are then shipped to a VAX-11/750 superminicomputer running the VMS operating system. Data buffers include a header which, among other things, identifies the type of data. Examples of data buffer types are BEGIN RUN, EVENT DATA or ANGLE STEP (in the case of the K-800 magnet mapper).

The framework of the data acquisition system therefore consists of a data routing program (ROUTER), several system supplied programs (Non transient tasks), the user interface (Transient programs), and a terminal sharing facility (NOTIFIER).

A. ROUTER

We have written a data routing program. This program acquires data buffers from front end computers, and supports up to eight output data streams which may be connected to data analysis processes. A data stream is a buffer notification mailbox, a collection of buffer types to be routed to the stream and, when connected, a consumer program run as a subprocess to ROUTER.

ROUTER acquires data into VMS global sections (shared memory regions). When a buffer arrives, it checks the buffer type and sends buffer notification messages to the stream mailboxes of all consumer programs to which data buffers of that type should be sent. The notification message contains, among other things, the name of the global section which holds the data, and a serial number which also identifies the section. These will be discussed in detail later. Stream consumer programs can use this information to map to the buffer and access the data.

When a buffer notification message is sent to a stream, a reference count for the buffer is incremented which prevents ROUTER from queueing that physical buffer for new data until all consumer programs receiving that buffer have sent buffer done messages back to ROUTER through a buffer acknowledgement mailbox.

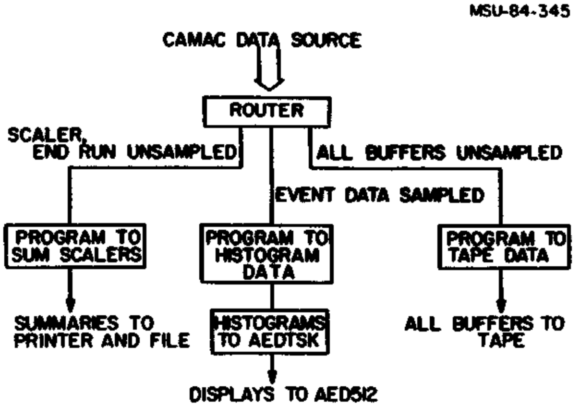
Interface functions for user programs include procedures to open a data stream, get a buffer and return an acknowledgement message. Additionally, programs may request that a subroutine be called at Asychronous System Thap (AST) level whenever data is present. The buffer acquisition routines keep a table of virtual addresses mapped to physical buffers so that the VMS global section mapping routines are only called the first time a process sees data in a given physical buffer. The buffer serial number is used as an index into the section lookup table to either return the buffer address to the caller (if the address is non zero), or to determine that the buffer is 'new' and must be mapped (address is zero).

Consumer programs are run as subprocesses to ROUTER, which means that ROUTER is notified when a consumer exits for any reason (FORTRAN STOP or bomb). When this happens, ROUTER decrements the reference count for each buffer which is in the exiting processes' stream queue and stops sending data to the stream. This prevents loss of physical buffers due to process exit.

In addition to requesting buffers by type, a program may receive data buffers in a sampled mode. In this mode, a buffer is only sent to the stream if all previously sent buffers have been processed. Thus a program receives data only as fast as it is able to process it. Some buffer types may be sent sampled while others are not.

B. Non Transient Programs

In addition to the histogrammer, several system supplied consumer programs have been written. These programs perform such operations as event recording, scaler summing, and data stream error detection. By making these programs stream consumers, it is easy for the user to substitute alternatives should the system written code not be suitable for a given experiment. An example of a relatively typical set of consumers during data acquisition is Fig. 1. Note that the box HISTOGRAMS to AEDTSK represents a histogram display program which was reported on last year[5]. A brief summary of each of the system written consumers is given below.



The event recording program puts all raw data on tape in an exact image of the incomming data. The tape program maintains a primitive file structure as follows: 1. Each run is separated by an end of file from following runs, 2. Each pause in the run (indicated by a pause run buffer) closes the tape by writing two end file marks and backing over them, 3. the logical end of tape is marked by two end file marks, 4. two end file marks are placed after the physical end of tape mark.

The scaler summing program simply totals incremental scaler buffers and, at the end of run prints out run totals and selected ratios. A set up file currently describes the scaler assignments and ratios requested.

An error checking program ensures that buffers arrive in sequence, and that buffer checksums match the buffer data. This provides a check on the communication link between the VAX and the front end processor.

C. User interface

The routing system is controlled by extensions to the VAX's DEC Command Language (DCL). When ROUTER starts executing, it creates two buffers, and queues them to a front end. It also posts a read on the mailbox ROUTER-INPUT. DCL command extensions directed at ROUTER are forwarded to this mailbox. If a program wishes to request a command function from the ROUTER, it may also write a valid command here. ROUTER understands the following commands:

1. MAKE	Creates a named stream. Router allocates two new buffers when this command is entered.
2. SEND	Requests that a list of buffer types be sent to a named stream. Buffer's may be sent sampled or unsampled.
3. CONNECT/CONSUMER	Connects a consumer program to a named stream. Router will continue to send data to the stream until the program exits.
4. LOAD	Loads a program into the front end processor.
5. ROUTER	Starts the ROUTER program.
6. FNA	Requests the ROUTER to perform a CAMAC function. (Useful for module checkout and setting up CAMAC settable devices.

D. Terminal Sharing

Since ROUTER and its associated stream consumer programs are run as subprocesses, the user's terminal is available for other functions. This allows us to meet the requirement that the system be modifiable on the fly in a very convenient manner. Without leaving the terminal, the experimenter edits what needs to be edited, compiles and links whatever needs to be compiled and linked, stops the old consumer program and restarts the new consumer program using the DCL STOP and ROUTER CONNECT/CONSUMER commands.

This leaves open the question of what a consumer program does when it needs to communicate with an experimenter. When ROUTER starts a stream consumer program as a subprocess, it looks for /INPUT and /OUTPUT qualifiers on the command line. If present, these provide logical names for the standard input and ouput/error units for a program. If names are supplied, then ROUTER checks to see if they translate to something already in existence (disk file or device), if so then ROUTER simply assigns this to be the input or output device. If on the other hand, the name does not have any translation, ROUTER creates a mailbox giving it the supplied name and makes that mailbox the default input or output device for the process. If /INPUT is missing, the program's input device is the null device, if /OUTPUT is missing, the program's output device is a mail box called SYS-OUTPUT.

A process called NOTIFIER is usually started up along with ROUTER, it's function is to read everything from the mailbox SYS-OUTPUT and broadcast it to the terminal. This little legerdemain allows consumer programs to do ordinary FORTRAN TYPE statements to get a breakthrough write generated at the user's terminal. The text supplied to a breakthrough write will appear on the device regardless of read and write requests in front of it in the device queue. Thus, for example, if one is editing and a stream program dies, its error messages will appear in the middle of the editing session rather than when the user exits the editor (potentially never). By default ROUTER itself sends all output to SYS-OUTPUT.

An additional DCL command extension; CONNECT/TERMINAL allows one to connect the keyboard of the terminal to any mailbox. This provides a way to get commands into a program. The connection is maintained until a control-Z is typed.

IV. Performance and experience

The system's performance to date should be measured by how it meets the design goals laid down at the beginning of this paper as well as how well these design goals meet the needs of experiments performed at NSCL. In addition, the speed of the system is always important.

In addressing the fit of the system, as implemented so far, to the design goals, we take up the challenge point by point:

1. Data can be put on tape, disk or any other device for which there is a VMS device driver. Programs exist to write 1600 and 6250 bpi event tapes in raw buffer image format, but since they are normal stream consumer programs, there is no bar to writing the data in any format on any device.

2. The system has accomadated without undue problems three data acquisition programs originally written in house before the ROUTER existed, and one outside user group which brought an online histogramming program with them.[6]

3. The system has run essentially unmodified for all nuclear physics experiments which have used the VAX since ROUTER was brought on line in early 1984. In addition, it was used to collect data from the K-800 magnet mapping system. It now appears that the ROUTER will not be suitable for use with the proposed streamer chamber due to the size of digitized events (as large as 1Mbytes). A simple replacement for ROUTER which supports programs requesting image samples has been constructed for this application, it makes use of many of the utility functions and programs developed to support ROUTER.

4. The software has run with three front ends requiring only minor changes in a single

subroutine. (These three front ends are the LSI-11 system, a 68000 based fast front end, and the K-800 magnet mapper).

5. The goal of no user programming has not been met yet. See next section on future work.

6 - 8. The multiprocessing data routing system meets these points more than adequately. Separation of system written and user written code into distinct subprocesses harnesses the interprocess protection schemes supplied by VMS. While the decision to implement system written components as standard stream consumers makes it easy for users to replace system written components if desired (a measure of the success of the system written components is that this has not occurred).

9. There is no privileged code, and only well documented VMS Run Time Library and System Service functions are called. When taking data, users are granted sufficient privilege to change their process priorities which allows data taking to suppress other users as needed.

10. The overhead is minimal since data is not copied to consumer programs. Additionally, the buffer serial number in the notification messages ensures that VMS is only needed to map the first occurence of a physical buffer to the address space of a consumer program.

Suitability: This is probably best measured by the fact that all experiments run at NSCL this year have made use of the system without complaint. In addition, the application of the system to the K-800 magnet mapper was a bonus that might not normally be expected from a system designed for nuclear experimental data acquisition. As indicated earlier, it will be necessary to do something different for streamer chamber experiments in view of the size of individual events

Speed: Current bench marks involving three consumer processes, indicate that the system should be able to take data and put it on tape at rates up to 400K parameters/second which is currently far in excess of the capabilities of our front end systems. At these rates, there would be very little time left for online histogramming. In more typical rates; ~10K parameters/sec, the system is able to leave about 80% of the compute time of a 750 available for user event analysis.

V. Direction of Future Effort

At present, there are directions in which the system must improve.

1. System supplied on line analysis (histogramming).

2. Experiment setup (Front end coding).

A. Histogramming

At present the on line analysis tasks are dealt with by programs written by experimenters. While some of these are quite general, they have a tendency to run slowly. This does not slow down the actual event rate since histogramming programs will generally take data in a sampled mode. But, since these programs are often used to read back event tapes, a computing bottleneck results on the analysis end of an experiment.

Work is currently underway on a high speed general histogrammer. A novel feature of this program will be the emphasis on parameter driven histogramming rather than spectrum driven histogramming. In spectrum driven histogramming, one loops over all defined spectra and gates and checks for the parameters which contribute to the spectrum, or are needed for the gate, while in parameter driven histogramming, one loops over the parameters which are present using them to select lists of gates to check and spectra to histogram. In experiments where the parameters present are relatively sparse, parameter driven methods should be faster since less checking is needed to determine which channels of which histograms need to be incremented. Even when parameters present are relatively dense, one gains with the parameter driven approach since the spectrum driven method typically still checks for parameter presence.

B. Front end Programming

While progress has been made in front end programming with the addition of the 68000 based fast acquisition front end, it is still necessary for an experimenter to known intimately the programming requirements of each CAMAC module used in an experiment. Work is currently under way on front end program generators. The program generator under construction would prompt users for the CAMAC configuration of the experiment, and the names of each signal input to each CAMAC module. The experimenter would the describe the physical parameters to be read for each event type (e.g. event type 1 should read Tel1 DE, Tel 1 E and Tel1 T). The program generator would access a database of the programming requirements of CAMAC modules and construct a front end program to read the data as specified.

VI. Conclusions

We have detailed the progress made on data acquisitions software at NSCL in the past year and outlined our plans for the extension of data acquisition software in the future. The buffer router based system seems to meet all of the current needs and the bulk of the perceived future needs in an elegant fashion. It provides speeds far in excess of the ability of front end processors to supply data and distributes the data in a flexible fashion to the selection of programs most appropriate for each experiment.

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FAST DATA ACQUISITION SYSTEM

A. Vander Molen, R. Au, R. Fox, T. Glynn

Abstract

A new fast intelligent multiprocessor data acquisition system has been installed. The system is based on the MC68010 using the VME bus and can tranfer data via the CAMAC dataway at rates up to 800 Kbytes/sec. The system has a user friendly interface which builds the required assembly code needing only the CAMAC FNA's used in the experiment. In addition the system can be easily modified using the standard MC68010 assembly language to handle most preprocessing requirements.

1. Introduction

The previous data aquisition system at NSCL was based on an LSI-11/23 preprocessor linked to a VAX-750[1,2]. As previously reported this system would not meet the data rate requirements of some of the experiments to be run at the lab. In addition, the modification of the software for each experiment often required the services of a programmer. To rectify these problems a new preprocessing system has been designed and built. The design criteria of the system were:

1. High data rates on the order of 400 Kbytes/sec.
2. Intelligence which would allow gating, pedestal subtraction and other like functions.
3. Versatile in that it must accomodate the wide variety of experiments run at NSCL.
4. Easy for the experimenter to set up and run.
5. Have an extensive debugging mode.

Additionally, we wanted to keep the impact of the conversion to the new system on the experimenter at a minimum.

2. System overview

The old data acquisition system had a Digital Equipment Corporation LSI-11/23 controlling the data transfer from a CAMAC crate to its memory. Following an initial event trigger, the LSI-11 decoded a bit register and read selected devices based on its pattern. Data was blocked in 8 Kbyte buffers which were sent to the VAX via a CAMAC serial highway system. In addition the LSI would at periodically transfer scaler buffers and respond to START, STOP and TAPE commands. The new system operates in essentially the same manner. However two or more MC68010 CPUs residing on a VME bus replace the LSI-11 system. This system controls the CAMAC crate via a crate controller designed and built at NSCL. It again builds an 8 Kbyte block of data to be transferred to the VAX. After a block of data is acquired by a CPU it then gives control of the CAMAC system to the next CPU which begins to acquire data. The former CPU concurrently transfers its data to the VAX via a second bus. Thus the two processes (acquisition and transfer) overlap reducing dead time considerably. The VAX receives the data via a FIFO located in a second CAMAC crate linked to it through a CAMAC serial highway. The old LSI system resides in this crate and continues to periodically read scalers and process the user control commands. If preprocessing requirements (after a block has been acquired) plus transfer time exceed the acquisition time another processor can be added to the system to maintain maximum throughput.

3. Hardware.

The hardware is composed of three major sub systems. The first is the VME crate which houses the MC68010s and part of the CAMAC crate controller. The second part is the CAMAC crate which contains the data acquisition modules and the remainder of the VME to CAMAC crate controller. Finally there is a CAMAC crate containing the scalar modules, the LSI-11/23 system and a type L-2 crate controller linked to the VAX. In addition this crate houses the FIFOs which are linked to the MC68010s via a separate bus.

3.1 VME Crate

Motorola VME 110 MPU boards were used and configured with 10 Mhz MC68010 CPU's, 32 Kbytes of EPROM and 32 Kbytes of RAM. The CPU boards along with a VME bus controller board, a 4 Kbyte memory board and the CAMAC controller interface resides in a 9 slot VME bus crate. With the exception of the CAMAC controller the hardware can be commercially obtained.

3.2 CAMAC Crates.

The remaining components of the system consist of two CAMAC crates. The first is linked to the VME bus by the VME/CAMAC controller and houses the ADC's, TDC's, etc. used in experiments. The second crate contains the scalar modules, the "button" box used to start and stop the experiment, the LSI-11/23 system, the L-2 crate controller linked to a VAX 750 and a NSCL designed CAMAC module that links the CPU boards with the second CAMAC crate. This structure is similar to the previous system except the MC68010 controls one of the CAMAC crates rather than LSI-11/23.

4. Software.

The software for the VAX and LSI-11/23 is described elsewhere[1,2]. This code was only modified to account for the MC68010 system and remains essentially the same in structure with the data acquisition code removed. The new code is comprised of three parts; the monitor, the executed code and the code generator. The monitor resides in VME110 EPROM and is used to load and debug code. The executed code controls the experiment, reads the data and transfers the data to the FIFO. The code generator is a user friendly program run on the VAX which prompts the experimenter for pertinent information about the experiment and then generates the assembly code for the data acquisition program of the MC68010.

4.1 Monitor.

The monitor was devoloped using the Motorola TUTOR or MACBUG as a basis. The program was modified to account for the MC68010 as opposed to the MC68000. In addition the monitor automatically loads and executes the acquisition program on RESET. The monitor allows the setting of breakpoints, tracing, program assembly, disassembly and modification as well as the examination and modification of memory and registers. These features are a powerful tool in debugging the system.

4.2 Experimental code.

Because of the flexibility of the MC68010 instruction code a wide variety of programs can be written. However, since most experiments run at NSCL have similar structure a skeletal code was written that is then tailored to each experiment. This code was written to optimize the speed of data aquisition. The code waits for a LAM indicating an event and then reads a bit register decoding its pattern to determine which modules must be processed. At the completion of the event it determines if there is still enough room in the buffer for another event and continues if there is. If not the CPU gives up control of the CAMAC to the next CPU and proceeds to generate a buffer of data for the VAX. While this is occurring the other CPU is taking the next buffer of data. This concurrent processing reduces the dead time tremendously. When a full buffer is sent to the FIFO the VAX receives a LAM and proceeds to read the FIFO. The CPU meanwhile has gone into a wait state until the VME bus is again available to take data. This process continues until the LSI signals the MC68010 to stop.

4.3 Code generator.

To facilitate the tailoring of the 68010 code to experiments a user friendly program was written to run on the VAX. This program allows the experimenter to input the NAF's required to initialize, clear, read and write to CAMAC modules without having to do any coding. The data set generated can be saved and modified later. This procedure has the advantages of insuring the integrity of the code, the speed of the code and allows the code to be tailored by persons other than programmers.

To use the program the user executes a command file on the VAX which in turn prompts the user for NAF's to be used in the experiment at certain logical points i.e. initialization, end of event and the NAF's used to read data for each bit triggered in the bit register. The code generator then generates macros from this data. The command file continues with the assembly and linking of the program. The resultant code is subsequently downloaded to the MC68010.

5. Performance evaluation.

Each element of the system was evaluated using different criteria. Data acquisition software was evaluated based on event dead time. Usability and tailoring time was used for the code generator program. Finally the monitor was evaluated in terms of its usefulness in debugging.

5.1 Data acquisition.

Bench tests of the system have shown that 16 bit data can be transferred from a CAMAC module to memory in 2.6 microseconds or approximately 800 kbytes/sec. Data transfer rates to the FIFO have been shown to be about 250 kbytes/sec. In actual experiments[3,4] there was no difference. Experimental event dead time, which includes 80 microseconds for the ADC conversion time, was found to be 160 to 200 microseconds for 5 to 12 parameter events. It should be noted that this also includes some software overhead for processes other than data transfer, i.e. multiprocessor communication, buffering, headers, etc. The actual data transfer rate to tape over a typical period of 1.5 hours was on the order of 800 events/sec while remaining 77 percent live using a single CPU. Transfer rate up to 4000 events/sec. were seen at 5-10 percent live. In the second experiment 2 CPUs were used and the event size was twice that of the first. Its data rates to tape were found to be on the order of 1000 events/sec at 80 percent live. In both experiments factors other than the computer (pileup/chance coincidences) limited the data rates of the experiment. A third experiment using 5 microsecond ADCs had a dead time of 62 microseconds which indicates the minimum time for the software. Note that the software algorithm used was the general purpose algorithm and a faster algorithm could be used for fixed event types reducing this time even further.

5.2 Experiment software development and debugging.

Development of the experiment software using the user friendly software requires about 15-20 minutes to respond to the program input requests, compile and link. An additional 15-30 minutes were required for special modifications. This indicates that typical experiments can be set up in less than an hour with a non programmer doing most, if not all, of the work.

The debugging software was shown to be a major benefit during development and set up time. The ability to set breaks, trace the program and examine data during the acquisition of an event proved to be an invaluable asset in determining both software and hardware problems.

6. Future developments.

The major bottlenecks in the data transfer rates are in the FIFO and CAMAC serial highway. A new system is being designed that removes these problems. Essentially the new system will take advantage of the new VMX bus with its 16 bit data path and a DRV11 parallel data path to the VAX. In addition the LSI-11/23 will be replaced with a MC68000 based system. This new system will then eliminate the I-O channel and the CAMAC serial highway. Additionally by increasing the memory a faster algotrithm can be used leaving the ADC conversion time as the major dead time componant. Software changes to the user interface will also make code easier for the user to develop and implement.

7. Conclusions.

The system as a whole performed as expected and was well received by the experimentalists at NSCL. The data acquisition system is no longer the limiting factor at NSCL in terms of data rates and is easy to set up and modify. Data acquisition (CAMAC to memory) is at the rate of 800 Kbytes/sec. after the ADCs have settled. Data transfer to the VAX and tape is restricted by the FIFO and serial highway speeds to 250 Kbytes/sec.

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FAST γ-RAY DATA AQUISITION WITH THE 68000-VAX SYSTEM

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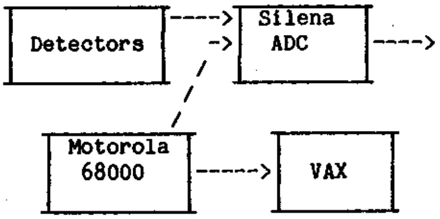
In the recent work on γ-ray spectroscopy of neutron deficient odd-odd deformed nuclei (NSCL Exp.'s #84017 and #85016), data were taken with Silena ADC's (model 7420/G) interfaced with the Motorola 68000-VAX data aquisition system. The computer codes for the two systems were assembled from the modular type code components and modified for the specific use of γ-ray data aquisition by R. Fox and A. Vandermolen.

The 68000-VAX system proved itself as a satisfactory method for fast γ-ray data aquisition handling count rates at times in excess of 60,000 counts/min. The event by event recording method should allow for coincidence data aquisition without extensive filtering by pre-computer system electronics.



A block diagram of the system.

STATUS OF NUCLEAR ELECTRONICS CONSTRUCTION

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As the experiments at the K500 and in the future of the K800 become bigger and more complex, more and more electronics will be needed. A compromise must be found therefore between building, an activity limited by manpower, and buying, which is limited by the budget. We have built "simple" electronic modules, where construction is much less expensive than buying, and "special" modules, which are not available commercially. We have also involved industry in building generally useful electronics for the type of experiments done at NSCL.

Simple General Electronics

Modern multiparameter experiments tend to adopt the high energy physics architecture. In this kind of experiment many detectors with relatively simple electronics and many ADC's and TDC's are used. There, a "event" is defined as a "pattern" of detectors that have had useful information (hits). To instrument such experiments, one needs a preamplifier, a main amplifier or shaper, a discriminator, an analog to digital converter (ADC) for every detector. In an actual experiment, patterns must be identified as fast as possible, so that the analog energy pulses do not have to be delayed too much. Therefore one needs fast discriminators and fast logic operations (e.g. Boolean AND) to minimize the amount of cables needed to delay the analog signals. Here it is important that the propagation delay through these units is minimal, not so much the rate capability.

We have built 20 four fold four input logic boxes (4X4 box) originally developed at LBL by one of us (M.M.). One channel of this unit generates the Boolean AND function from four inputs. As inputs,one can select the input signal itself or its complement. Therefore this unit can be used as four input overlap coincidence, as three input coincidence with one veto, etc, or as an O R gate (FAN IN). It also contains a oneshot which can be fired by the positive or the negative going edge of the AND output. It accepts fast NIM signals, and puts out four fast NIM and one Slow NIM signal. As an indication whether the oneshot has fired, a "blinker" is included which produces a lighflash of 10ms. This allows easy inspection of the working of an experiment. The propagation delay from input to AND output is less than 5 ns, to the oneshot output less than 10 ns, and to the slow NIM output less than 15 ns. The width of the oneshot pulse can be varied from 20 ns to 40 µs. Commercial coincidence units usually have longer propagation delays.

In addition we have started building cable delay boxes, with delays ranging from 8X10 ns and 8X20 ns in a NIM module to 20X100 ns in a 19" crate.

Prototypes of a quadruple gate generator have been successfully tested. This unit accepts fast NIM signals, and generates delayed fast and slow NIM signals, where the delay and the width can be varied between 10 ns and 100 µs. It also includes the "blinker". We intend to produce 20 of these modules, too.

Special Electronics

We have also built special electronics for some of the experiments performed in 1984: For the hodoscope used by K. Gelbke et al., we built divider-strings for Photomultiplier tubes and charge integrating preamplifiers which can be used in vacuum. To be able to mount these devices in vacuum, their power dissipation had to be minimized. In the case of the divider-strings this was achieved by using an "active divider" which includes source followers with

MOSFET's similar to a design published by Kern's[1]. The use of MOSFET's allowed to reduce the standing current in the divider to 150 µA, while still presenting a impedance of less than 1KΩ to the "upper" dynodes. The bipolar transistors used in this application up to now require higher currents to produce comparable low impedances. In our version the socket assembly was built separately from the divider, minimizing heating of the phototube, and reducing the space requirement at the phototube. This allows close packing. The gain shifts observed with this arrangement in an experiment using NaI detectors was less than 1% for count rates between zero and 50 Kc.

For the charge sensitive preamplifier, a low power version of the "standard" FET cascode circuit was used. 50 of these units were built and used successfully in experiments at MSU, ORNL and GANIL.

For an experiment at ORNL 8 Particle Identifiers follwing ideas of B. England were built.[2] These allow moderately fast identification of particles in experiments using Silicon Detector Telescopes. They were used in this experiment to suppress the large α-particle background by generating a fast veto signal from the output of the identifier. This will be the basis for a more general Particle Identifer unit.

For an experiment at LBL, where phoswich detectors with CaF_2 and plastic were used, a suppression circiut for events were only the plastic scintillator fired was built. It sucessfully suppressed neutrons and gamma rays hitting these detectors. However, since the Phoswich arrangement uses now a Fast/Slow Plastic Telescope, this unit will not be needed, therefore this project will not be continued at this time.

To analyze the pulse shapes coming out of the Bragg Curve Spectrometer in the 4π Detector, we started building a wave form analyzer. This is based on the use of a 9 bit 20Mc flash ADC (TRW), and includes also a memory for 256 samples. This unit will also be used to study pulse shapes of the scintillators NaI or CsI and BaF_2 to investigate the usefulness of pulse shape discrimination as a technique for particle identification.

Finally an interface between the CCD cameras for the Streamer chambers experiment and the 68000 Data acquisition is being finished. This will be used to study electronic storage of Streamer chamber pictures.

Outside Fabrication

In discussions with several commercial companies new models which would be useful for the experiments at NSCL were proposed. At this time a quadruple Constant Fraction Discriminator, a quadruple "Silicon" Preamplifier with selectable gain and calibration facilities, and a "fast-slow" amplifier which includes a slow shaper for energy measurements, and a fast timing filter amplifier for timing measurement have been produced by Tennelec. These units have all been used successfully in many experiments at NSCL and elsewhere. We are involved in discussions about the commercial production of our logic unit and the gate generator.

Further Developments

It is expected, that future experiments, where many detectors will be used - e.g. the 4π Detectors - will require the construction of more units containing multiple channels of electronics. We intend to proceed in this direction, the first step being a Octal Constant Fraction descriminator.

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DEVELOPMENT OF CCD CAMERAS FOR STREAMER CHAMBER

S. Angius, G. Crawley, M. Maier, V. Rotberg, R. Tickle, G. Westfall

There are a number of reasons to consider the use of CCD cameras for streamer chamber experiments. Among them, the advantages of a much larger dynamic range of intensity measurements (4096 for the 12-bit system currently under development here, compared to a value of about 20 which is normal for photographic film), and of a linear response to light. Both these characteristics should improve the charge identification capability of the streamer chamber. Also, the higher sensitivity of the CCD's allowes the operation of the streamer chamber at a lower voltage, i.e. closer to the avalanche mode, where a better proportionality exists between the intensity of a particle track and the primary ionization. Perhaps even more important, the output of a CCD is in digital form, and can be directly recorded on tape, thus avoiding the time-consuming processes of developing the film and digitizing the images.

The three-dimensional reconstruction of an event requires that at least two exposures be taken from different positions. Normally, in the LBL streamer chamber, three cameras operate simultaneously and therefore three identical CCD systems will be used. A scheme of the final set-up is shown in Fig.1, where the elements outside the dashed contour are part of the LBL streamer chamber apparatus. When the trigger electronics sends a pulse to indicate the occurrence of an event of interest, the cameras will start an exposure, and the CCD's will then be read out into the first half of the 1 Mbyte memory (a CCD consists of 384x576 pixels, and the intensity information from each pixel is stored in one word of memory). The other half will already contain a typical background frame, which will be subtracted from the raw data, and the resulting values compared to a predetermined threshold, before the processed frame is transferred to the dual-ported memory. At this point, the downloading of the processed frame to the VAX and the read-out of the next exposure from the CCD's can proceed simultaneously, thanks to the use of the dual-ported memory boards. It is hoped that the on-line processing described above will reduce the amount of data to be transferred to tape by at least 30 to 40 %, thus making both the recording and the subsequent data analysis more manageable.

The camera heads and associated electronics modules were received from Photometrics Inc. in August 1984. Since then, one CCD interface and one DR11W interface have been built at MSU. The first board is a CCD camera to VME interface, and allowes on-line operation of the cameras, through a one-word command input register and a one-word Z-digital output register. The second interface provides for high-speed parallel transfer of data from the dual-ported memory to the VAX-750-data2 machine. To complete one system, one 1 Mbyte and one dual-ported memory boards have been purchased, and the necessary computer codes developed. Therefore, at the present stage, an exposure can be taken, the entire CCD, or any subarray within it, read out, and the intensity information transferred to the dual-ported memory. From here, the downloading to the VAX through the DR11W interface takes about 3.5 μsec per word. The VAX file created can be displayed later on an AED terminal. An example of such a display is given in Fig.2.

Currently, the necessary electronics boards for the other two systems are being assembled or have been ordered, and most of the software is ready.

A thorough test of the system, especially of the timing of the various operations, requires some further developing. A trigger

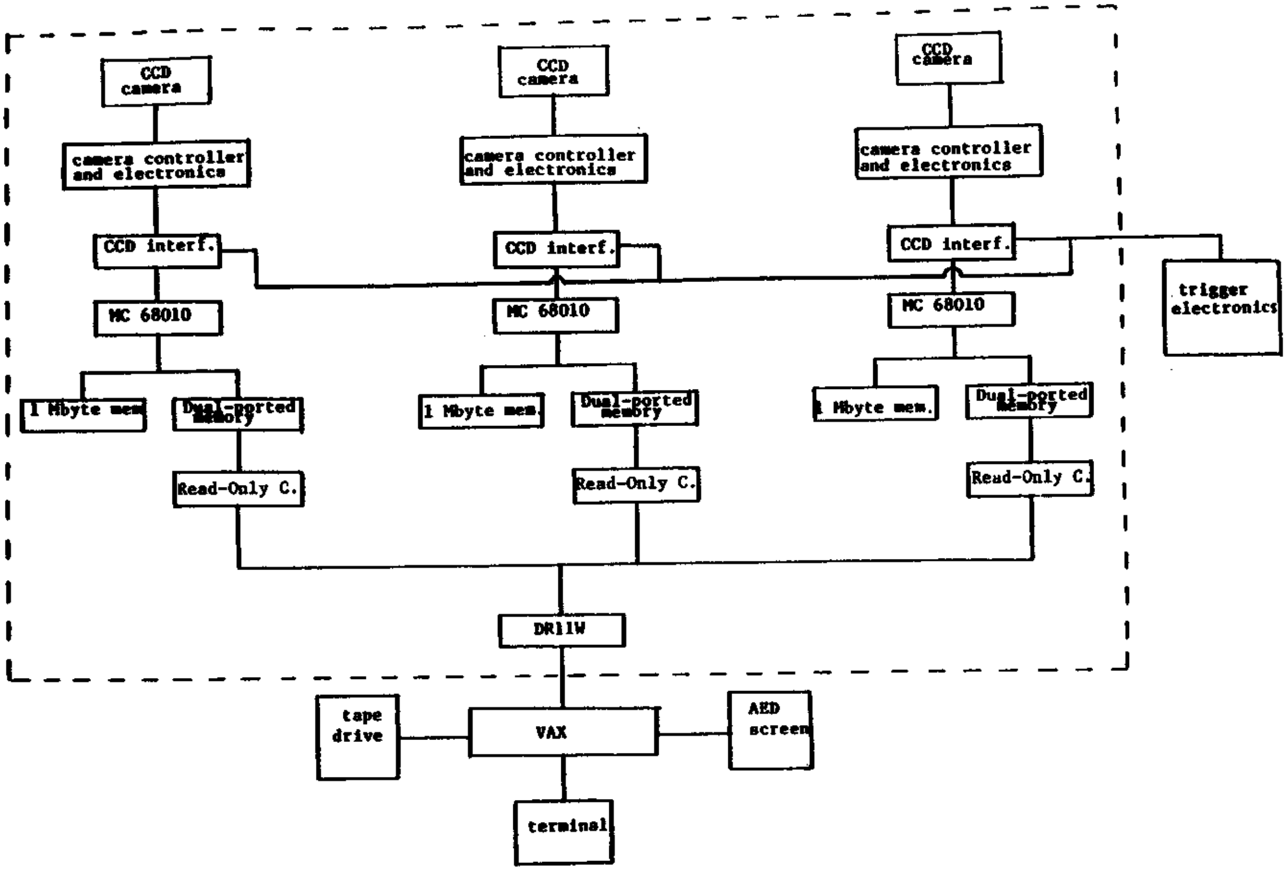


Fig.1- Electronics set-up for a streamer chamber experiment. The parts inside the dashed contour are currently being developed at MSU.

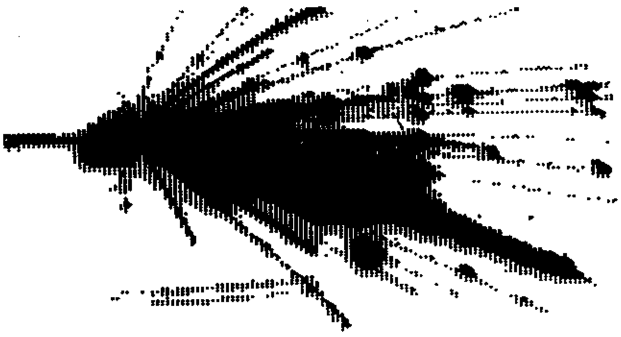


Fig.2- Example of picture taken with a CCD camera.

pulse must be simulated, and made capable of sending requests for different interrupt levels to the microprocessor, so that the different tasks required can be performed. The final step of the development of the system will be the testing of the simultaneous operation of the three cameras, with a central "control" program coordinating the various tasks through a number of routines in the microprocessor.

InSb AS a γ-RAY DETECTOR

Wm. C. McHarris

As improvements in the performance of Ge as a γ-ray detector become smaller, one looks toward other semiconductors. Among these, InSb offers tantalizing possibilities for greatly improved resolution, peak-to-Compton ratios, and efficiency, but it also has some formidable drawbacks. Its properties are compared with those of other semiconductors in the following table:

Semiconductor Properties at 290 K

	Si	Ge	GaAs	InSb
Effective Z	14	32	32	50
Band Gap (eV)	1.106	0.67	1.35	0.17
Lattice Constant (A)	5.42	5.65	5.65	6.48
Electron Mobility ($cm^2/V \cdot sec$)	1350	3900	6800	80 000
Hole Mobility ($cm^2/V \cdot sec$)	480	1900	680	4 000

In principle, InSb should be superior to Ge by roughly the following factors: Resolution, 4X; Peak-to-Compton ratio, 25X; Efficiency (per mole), 9X. However, the factor of 20 between its electron and hole mobility has prevented it from being seriously considered until recently: Rather than drifting p-type InSb with Li^+, one would have to drift p-type with an anion, and even the smallest, F , would not allow for effective drifting at the low temperatures necessitated by the small band gap. In addition, the discrepany between carrier mobilities would result in a geometrical factor entering into the completeness of charge collection, affecting the resolution. Resolution would deteriorate with increasing γ-ray energy as the photons penetrate more deeply into the crystal. Two recent developments suggest, however, that we take a closer look at InSb. 1) Pure enough crystals are now available to be used as "intrinsic" detectors, although these are so small that their use has been limited thus far to infrared radiation. 2) The "Pulse-Height Correction Method," developed in our laboratory to compensate for incomplete charge collection from radiation-damaged Ge detectors, has been found to compensate as well for geometrical effects on resolution. Developing a practical InSb γ-ray detector will not be trivial, especially because of the difficulty in obtaining reasonably uniform larger crystals of mixed (III-V) semiconductors. Nevertheless, if even a fraction of the "on paper" improvement over Ge could be realized, InSb could become an important γ-ray detector. We have arranged to obtain small InSb crystals from Texas Instruments and to demonstrate that they can be used for γ-ray detection.

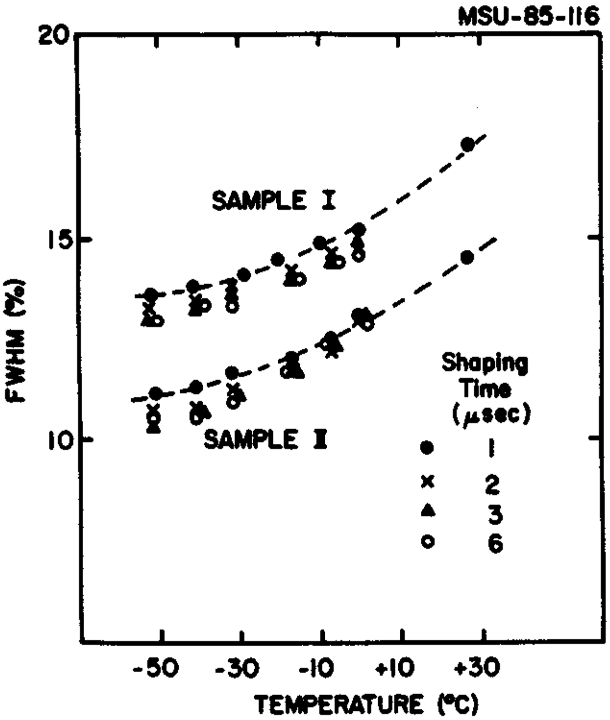
ENERGY RESOLUTION OF BISMUTH GERMANATE DETECTORS AT LOW TEMPERATURES

H. Utsunomiya and D.J. Morrissey

We report on measurements of the energy resolution of bismuth germanate (BGO) detectors at low temperatures (down to -50° C). This work was done in connection with a performance study of candidates (BGO detectors) for the gamma-ray multiplicity array.[1] We chose for study the following two samples: I) Bicron Co., disk 3/4" diameter X 1/2" thick BGO crystal coupled with a Hamamatsu TV Model R1166 PM tube and II) Rexon Co., 3/4" X 3/4" X 1" thick BGO crystal coupled with a Hamamatsu TV Model R1450 PM tube. At room temperature, sample I and sample II had energy resolutions of 17.3% and 14.5%, respectively, (full width at half maximum) for a ^{137}Cs gamma radiation (662 KeV).

The two complete detectors were placed inside a temperature controllable refrigerator with a ^{137}Cs source. Signals were sent to a ORTEC Model 572 spectroscopy amplifier and whose output was analyzed by a CAMBERRA SERIES 35 MCA. +1000 V was applied to the PM tubes. The temperature dependence of energy resolution of the two samples was studied for a variety of shaping times of the spectroscopy amplifier, because the time constant of the light emission depends on temperature.

In Fig.1, the measured energy resolution is plotted against temperature. The dashed lines connect data points obtained with a shaping time of 1 μsec to guide the eye. At -52° C, energy resolutions of 13-13.5% and 10.3-11.1% (FWHM), slightly depending on the shaping time, were achieved by sample I and sample II, respectively. Note that longer shaping times yield better resolution at lower temperatures. Relative improvement in the energy resolution due to the cooling seems comparable to or slightly less than the result reported in Ref.2. However, the energy resolution achieved by sample II at -52° C is remarkably better than the result (14.1%) obtained at -78° C reported in Ref.2. The slight improvement of the energy resolution with increasing the shaping time seems associated with the report in Ref.2 that the decay time of scintillation light becomes significantly larger at low temperatures. Overall, the change in resolution with temperature is consistent with the change in photomultiplier tube noise and the change in light output from the crystal.



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PARTICLE IDENTIFICATION WITH BARIUM FLOURIDE

J. Yurkon, D. Morrissey, M. Maier, H. van der Plicht, G. Westfall

Barium fluoride (BaF_2) is of interest as a possible charged particle detector medium due to its:

1. Fast 600 psec. 220 nm component offering fast timing capabilities.
2. Good energy resolution[1]. About 30% less than for NaI.
3. High gamma-ray efficiency.
4. Possible particle ID by pulse shape analysis.
5. Low cost.

We have made a preliminary test of BaF_2's ability to provide a particle ID signature. The crystal used is 0.5" long by 0.75" diameter. It was coupled to a Hamamatsu R1668 1.0" diameter, quartz faceplate, photomultiplier. The photomultiplier was coupled to the BaF_2 crystal using RTV 615 silicone rubber. RTV 615 has been shown to have adequate transmissivity in the 220 nm region.

Tests of various optical coupling media were done to assure that the 220 nm peak would not be absorbed. We have tested a commercial optical silicone grease, and three different optical epoxies. The samples were used to couple two 1/16" thick S1-UV quartz disks together and its transmission relative to a 1/8" thick disk was measured with an absorbtion spectrometer. The results are shown in Figure 1.

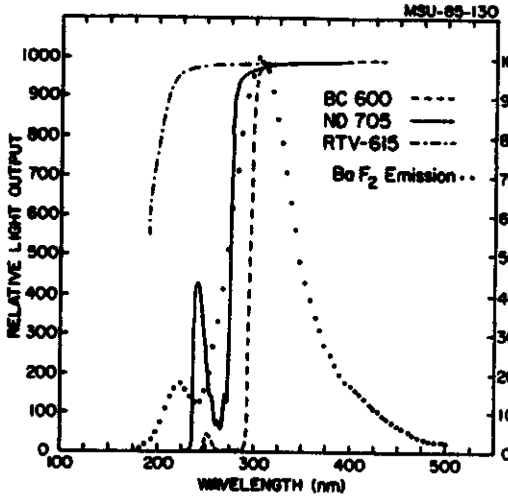

Fig. 1 Light transmission curves for various optical coupling compounds.

The crystal was covered with teflon tape to increase the collection of the UV scintillation. Teflon tape and Magnesium Oxide appear to provide the best reflectivity. Figure 2. shows the response of the BaF_2 crystal to ^{137}Cs. The FWHM response is approximately 13%.

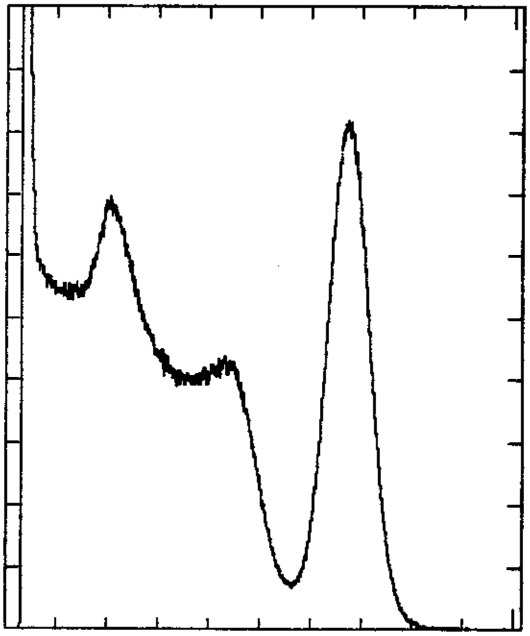

Fig. 2 Energy response of Ba F_2 to ^{137}Cs γ-rays.

The crystal was then used with a 30 Mev/A $^{12}C^{4+}$ beam on a Gold target. The fast and slow components were integrated with QDC's and the results are shown in Figure 3. The charge separation for p, d, t is not adequate. Alphas are clearly separated from p, d, t. Close inspection shows that the particle ID is not symmetric as one would expect if it was simply a problem of insufficient light collection. Also,

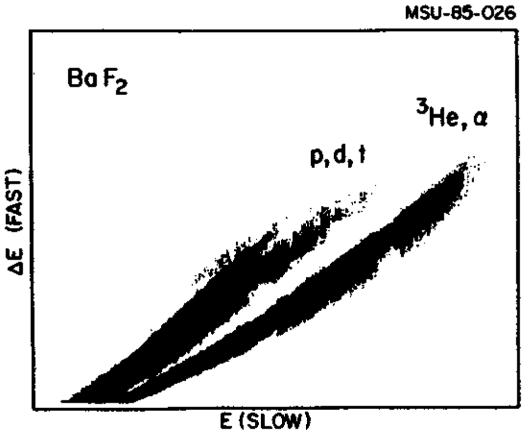

Fig. 3. Ba F$_2$ Particle identification spectrum.

the resolution seems to be independent of energy. This seems to imply a position depedence in the light collection but more tests have to be made to understand the real cause.

While BaF$_2$ has yet to show good particle identification it shows promise in situations where one would like to obtain both charge and time-of-flight. Disadvantages are that one must use hard UV optics.

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METAL JOINING TO SAPPHIRE AND CERAMIC

J.E. Yurkon, J.A. Nolen, C. Scripter

Insulators having a smooth transition to a metal support are needed for the K500 cyclotron extraction system. Corona rings with insulators pressed in have proven unsatisfactory. This paper will describe the technique used to join ceramics or sapphire to a metal.

The metal to be brazed to a ceramic must have an integral coefficient of thermal expansion, at the brazing temperature, which is close to the ceramic. Otherwise, it must be a very soft metal that can yield before fracturing the ceramic-metal bond. Molybdenum has the desired properties of being nonmagnetic, brazable, and having an expansion coefficient closely matched to alumina.

The alumina insulator is prepared by painting on an emmulsion of Molybdenum, Manganese, and SiO_2 in an organic binder. This is then heated to 1400 degrees Centegrade in a wet Hydrogen atmosphere for 30 minutes. This forms a gas tight metalization that can be brazed with proper preparation. A thin layer of Nickel is plated on the metalization to promote wetting of the Copper Silver alloy used in the brazing. The Molybdenum is similarly plated. The Molybdenum button is placed on the ceramic rod with a BT Copper Silver alloy foil disk sandwiched in between. This is held together in a stainless steel fixture which has been oxidized, (greening), to prevent the braze from adhering to the fixture. The fixture is then place in a dry Hydrogen atmosphere and heated to 850 degrees Centegrade with a controlled rate of rise and drop of temperature. This completes the brazing.

Sapphire is joined in a similar manner except that the MolyManganese is replaced with a Tungsten Oxide based metalizing paint HT-1WH made by International Technical Associates. The furnace is then heated to 1425 degrees Centegrade for 30 minutes in a 25/75 H_2/N_2 atmosphere with an 80 degree Fahrenheit dewpoint. The metal oxides reduce and form a metalized layer on the sapphire. The brazing operation is identical to that of the ceramic.

A LASER PULSER STABILIZATION SYSTEM FOR A MULTI DETECTOR ARRAY

J.E. Yurkon, S. Tanaka, G.D. Westfall

A calibration system for a large array of scintillators is under development. It will be used to gain stabilize approximately 170 scintillation counters.

A N_2 laser will be used to excite a piece of plastic scintillator similar to that used in the detector array. The N_2 laser has a wavelength of emission of 337 nm. This wavelength is completely absorbed by the plastic scintillator and the resulting emission is identical to that produced by a charged particle passing through the scintillator. The laser has a pulse width of 3 nsec. FWHM. This is fast enough so that when used with normal phototubes it has essentially the same pulse shape as a radiation induced scintillation. These characteristics are desirable since the spectral response of the photomultiplier is temperature dependant.

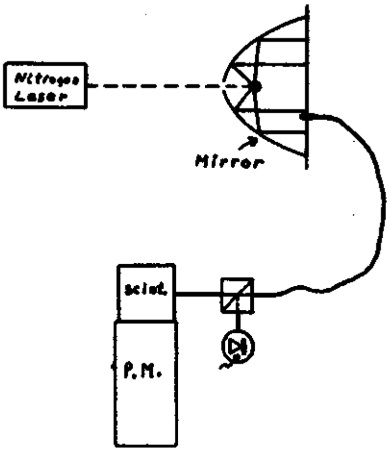

Fig. 1 A block Diagram of Laser Calibration System.

The laser is however, not a stable light source. At best it is stable to 8%. In order to be used as a reference the light output must be measured. See figure 1. The light from the scintillator is distributed to the detectors by means of fiber optic cables. The light at the detector end of the cable is split and measured with a PIN photodiode. The light is measured at the detector end since the transmittance of the cable is affected by bending.

Using this method we hope to obtain a cost effective gain stabilization system for a large detector array.