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# MULTIPLE-USER DATA ACQUISITION AND ANALYSIS SYSTEM*

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## Summary

The nuclear physics program at the Brookhaven National Laboratory High Flux Beam Reactor (HFBR) employs a pair of PDP-11 computers for the dual functions of data acquisition and analysis. The data acquisition is accomplished through CAMAC and features a micro-programmed branch driver to accommodate various experimental inputs. The acquisition computer performs the functions of multi-channel analyzers, multiscaling and time-sequenced multichannel analyzers and gamma-ray coincidence analyzers. The data analysis computer is available for rapid processing of data tapes written by the acquisition computer. The ability to accommodate many users is facilitated by separating the data acquisition and analysis functions, and allowing each user to tailor the analysis to the specific requirements of his own experiment. The system is to be upgraded soon by the introduction of a dual port disk to allow a data base to be available to each computer.

## Introduction

A CAMAC-based data acquisition system has been implemented at the Brookhaven National Laboratory High Flux Beam Reactor (HFBR) for nuclear physics research. It was based on the following criteria: 1) versatility, 2) commercial availability of hardware and software, 3) ready access to many users, 4) expandability, 5) dedicated data acquisition, and 6) flexible and separate data analysis.

Two computers of the DEC PDP-11 family with its well-developed software, along with various peripheral devices, are the elements used to satisfy the above criteria. The Unibus permits easy and low-cost access to peripheral devices which enables the scientist to configure the system to his needs. The configuration chosen at the TRISTAN facility consists of independent systems, one for data acquisition and another for data analysis. Past experience has shown that interaction between data acquisition and data analysis is best handled by separate and asynchronous systems. At present magnetic tape is the medium of exchange. In the future a 300 megabyte dual port CDC disc to allow a data base to be accessed by the two computers will be installed.

A CAMAC system for data acquisition allows versatility since commercially-manufactured modules are readily available. A Micro-programmable Branch Driver (MBD) couples the CAMAC equipment to the PDP-11 computer. The MBD can be programmed to satisfy the functional requirements of up to 8 independent data channels and allows greater flexibility by priority-driven software structured to handle each function separately.

The well-known, commercially-developed software available to DEC users is well documented and may be learned easily, allowing scientists to develop their own software on the analysis station if need be. There exist common routines which can be shared by others. The separation of the acquisition and analysis safeguards the data base and allows program development to proceed without possible deleterious effects. This system has been in use for two years and a sign of success has been the number of physicists who use the facility without the customary need for trained software and hardware specialists.

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The above configuration is used at present to do the following:

1) pulse height analysis (8192 channels), 3 available;
2) a two-parameter, time-of-flight (TOF) versus pulse height analyzer used for a fast chopper neutron experiment;
3) N-detector gamma-gamma-time coincidence and angular correlation system, where N may range up to 8;
4) an 8192 channel pulse height analyzer used in conjunction with a three (3) crystal pair spectrometer at the filtered beam facility;
5) four (4) multiscaler channels;
6) multispectrum analyzer accommodating 33-4096 or 17-8192 time sequenced spectra; and,
7) a block of scaler and interlock data.

The analysis system allows rapid plotting and listing of spectra, least-squares peak fitting, sorting of event-mode tapes to produce spectra for multi-parameter experiments, and decay curve analysis. Special users written routines may be readily introduced for specific functions.

## Description of Applications to Nuclear Physics Research

### TRISTAN

The on-line mass separator, TRISTAN II, is located at Brookhaven's High Flux Beam Reactor.[1] A surface ionization type ion source, which contains ~5 grams of $^{235}U$ is placed in an external neutron beam flux of approximately $2 \times 10^{10} n/cm^2/sec$, and is used to generate short-lived fission products. Experiments have been constructed on two of five available beam lines to measure $\gamma$ singles $\beta$-$\gamma$ and $\gamma$-$\gamma$ coincidences, $\gamma$-$\gamma$ angular correlations and delayed neutron emission. Three 8192 channel MCA's, 16 time-sequenced mutlichannel analyzers, 4 multiscalers, and a 3 parameter, $\gamma$-$\gamma$-t coincidence unit service the TRISTAN facility.

### Fast Chopper

The Fast Chopper is used for time-of-flight analysis of resonance neutron capture $\gamma$-ray studies.[2] Germanium detectors are placed at flight paths of 22 or 48 meters from the chopper. The recording of $\gamma$-ray events following neutron capture and their time-of-flight information are the two parameters of interest for this experiment.

### Filtered Beam

Filters for tailoring the neutron beam are contained in a 4-position rotary collimator external to the reactor shield.[3] A set of easily modified filters can be rapidly interchanged so as to span a broad range of neutron energies in a study of a single nuclide. A 3-crystal pair spectrometer is used to detect primary $\gamma$-rays from $(n,\gamma)$ experiments using the filtered beam. An 8192 channel multichannel analyzer for triple coincidences and a separate 8192 channel analyzer for singles is assigned to the filtered beam.

### Data Acquisition

With the decreasing cost of mini-computers and its associated peripheral devices it has become feasible to implement a computer configuration to meet the specific needs of each one of a large number of experimentalists.

CAMAC

Data are collected by NIM and CAMAC modules. The use of commercially-available equipment is a major guideline for this system. The CAMAC system was chosen because it allowed versatile experimental set-up at the front end of the data acquisition system. In most cases a simple interface adapts NIM equipment such as ADC's to CAMAC input registers so that logic levels and communications are compatible between them. The use of front end intelligence and memory storage in CAMAC reduces the dead-time for two or more simultaneous experiments. The latest literature of CAMAC modules from various manufacturers shows that the trend of pre-processing of data is now firmly established thanks to microprocessor chips and cheaper memory. This feature relieves the minicomputer from monitoring the data bus for every event. This is accomplished by the use of block transfer. An example of an intelligent module is the ORTEC MC024 CAMAC Memory Control which operates as the CPU of a complete data acquisition system. It provides routing, timing and logical control to either read or write data that are stored in memory. Operating modes provided by a front panel switch are Add-One-to-Memory (AOM) or store mode, also known as the list mode. Until Fast Bus is commercially available on a large scale, CAMAC and NIM modules suitably chosen can be configured to meet the requirements of modern nuclear physics programs.

Micro-Programmed Branch Driver (MBD)

A key device used to increase the rate of data acquisition is the Microprogrammed Branch Driver (MBD) which contains an arithmetic logic unit and 4K of memory.[3] The unit is commercially available from Bi-Ra. The MBD couples the CAMAC equipment to the PDP-11 computer. This unit provides 8 channels of priority interrupt to the CAMAC crates and provides servicing of an interrupt driven event, giving the control computer distributed computing power by delivering pre-processed data. The basic function of each program module is to collect the experimental parameters presented by that channel and perform simple operations on the event descriptors read in. The simplest operation is the buffering and subsequent storing of event descriptors on magnetic tape. Another operation is the incrementation of a memory word and the concommitant accumulation of a spectrum. The MBD micro-processor code comprises the largest block of non-FORTRAN software in this system.

Peripherals

The PDP-11 computer has a 16 bits word and communicates with peripheral devices as memory locations usually located in the upper 4K address space. The Unibus which connects all the peripheral devices is asynchronous and allows communication among the devices, independently of the time it takes for each unit to respond. This system is well-supported commercially and affordable peripheral devices are manufactured competitively. The peripherals attached to the data acquisition computer are:

2-mag tape units-used to list data and spectra, backup operating system, portable medium of exchange.
2-RK05-2.5 megabyte disks-used to store operating system and peripheral device handlers.
1-GT-40 display processor with a 19 inch display screen, featuring scrolling and vector graphics; it is also used in parallel with a typewriter terminal.
1-1 megaword of bulk core memory, used to store spectra, double or single precision data in an add-one mode.
1-Paper tape reader/punch, used for bootstrapping and diagnostics.
1-MBD-As explained above, it is useful for storing spectra in bulk memory without intervention of PDP-11, peripheral to peripheral transfer. Its main function is to couple CAMAC to the PDP-11 Unibus.
1-Silent 700 typewriter terminal, input of commands for starting and set-up of experimental parameters, with a hard copy option.
1-300 megabyte dual port disk, for mass storage has been purchased for installation. The disk will be viewed by both the data acquisition and data analysis computers.

In a multi-parameter data requisition system the usual bottleneck in data flow occurs in the list mode recording of data on magnetic tape. The tape containing event description must be scanned and the desired spectra reconstituted. Tape scanning is a time consuming affair. Instead of writing on tape, the information can be stored on disk. At 1600 bits/inch tape density, the disk is equivalent of 10 reels of magnetic tape. This dual port facility allows the data analysis computer to function independently on a common data base.

System Overview

The computer performs control, monitoring and I/O functions. The GT-40 displays information without the processor and the MBD stores data in the bulk memory directly. The 8 channels of the MBD for various TRISTAN and neutron physics experiments at the HFBR are described as follows:

Channel 0

Channel 0 has the lowest priority and is used as auxiliary pulse height analyzer. The address lines of a digitally stabilized ADC plus routing bits are interfaced to a CAMAC Input Register. The store pulse generates an interrupt and clear pulse is received from the Input Register when it is acknowledged by the computer. The MBD executes the appropriate code and accesses the 1 megaword bulk memory. This channel is used mainly for testing germanium detectors and miscellaneous experiments when necessary. A set of three fast ORTEC MC024 controllers and CAMAC memories are also controlled by this channel. These systems are self-contained and accumulate data without loading either the CAMAC data way or the unibus.

Channel 1 - Gamma Multiscale

This channel operates identically to Channel 0, except that one of 32 base addresses for data storage is selected. This base address is determined by the state of a real time clock, which is started by the time sequences of the TRISTAN moving tape collector. Thus 32 different pulse height spectra are generated, each corresponding to a different time region of a decay curve. The minimum time channel is 1/16 sec long. The analyzer also generates a spectrum which is time integrated over all channels. All 33 spectra, each consisting of 4096 channels, are stored in the megaword bulk memory for later read out. An option allows alternate use of 16-8192 channel spectra.

Channel 2 - Gamma-gamma Coincidence Analyzer

A special purpose interface accepts events from 1 to 8 detectors. The time relationship between individual events is also presented to CAMAC. A multiplicity switch selects (1-4) coincident events within a resolving time set from (40-2200) NS. Information

as to which detector participated in the coincident requirements is reflected in a status register which indicates to the computer via a LOOK-AT-ME (LAM) the appropriate Input Registers which contain the energy information from the corresponding ADC and TAC output. The MBD code stores these data in its memory buffer. When the buffer is full, its contents are sent to the PDP-11 which lists the information on magnetic tape and writes three spectra directly into bulk memory. The magnetic tape is later analyzed on the data analysis computer while the bulk memory contents is used to display spectra of interest to the scientist.

Channel 3 - Tailored Beam Pulse Height Analyzer

This channel is identical to channel Ø analyzer, except for its higher priority. This reserved channel for the tailored beam facility records pulse height via a 13 bit ADC.

Channel 4 - TRISTAN Multiscaler

This uses a real time clock with 128 time channels (minimum width 1/64 sec.). Four scalers are read and cleared at each clock interval, and the results stored in the megaword memory. After 128 clock cycles, the analyzer is reset for the next sequence. This analyzer is used for beta or delayed neutron decay curves.

Channel 5 - Neutron Time-of-flight Analyzer

The dual parameters of pulse height and time-of-flight for neutrons are used to examine radiative decay spectra from neutron resonances. Two NIM modules commercially available are used to present data to an input register of CAMAC. The descriptors are read into the MBD buffer area. The contents of the MBD are operated on in one of two ways. In direct sort mode, the buffer is immediately sorted by the PDP-11 into 3D spectra, either time or pulse height, with preselected gates entered via the keyboard. In the tape mode, descriptor words are listed on magnetic tape for off-line sorting.

Channel 6 - Scalers/Interlock

A set of 16 scalers is available to be associated with any experiment described above. These scalers may be used for beam monitors, total event rates, clocks. A 24 bit word is also read via a switch register and reflects some experimental conditions desired by the experimentalist. An example may be the termination of an experiment upon some preset condition. This channel is presented to the computer once every second by a 1 HZ pulse generator.

Channel 7 - Control

This channel which has the highest priority is used to initalize parameters in the MBD code, and to initalize and enable CAMAC equipment. This channel is also used to regulate control of the megaword memory which can be accessed either by the MBD or the PDP-11. A memory busy flag is set by this channel when the PDP-11 wants access to the memory. This flag prevents contention of bulk memory by the MBD and the PDP-11.

## Data Analysis System

Program development and data reduction can be done on the data analysis station. This second system consists of a PDP-11/34 computer with 128k resident memory, two 5 megabyte disks, two 9 track 800/1600 bits/inch magnetic tape units, one RF11 disk emulator, one Versatex matrix type line printer/plotter, one VT105 graphics display terminal and a typewriter terminal. Software operating system is the DEC RT-11 with FORTRAN.

A set of data manipulation programs is provided for the user in a library but the user is free to write his own data reduction program. Three main programs exist: DLK, PNLX and LINAL.

The DLK program is a general data array handling program. Transfers from peripheral in either binary or BCD form, setting up of displays, summing and shifting of spectra, and scanning event-mode recorded tapes, are some of the functions provided by this program. The PNLX program provides extensive plot capability on the Versatex printer/plotter. The LINAL program extracts centroids, finds peak regions and is in general a program to allow the physicist to mathematically manipulate his data.

With DLK, PNLX and LINAL, the user has minimum tools for spectra analysis. Most of these programs include simple algorithms which are within the range of the minicomputer. This facility provides the user the ability to analyze his data immediately and is time and cost effective.

A primary function of this computer is scanning event mode tapes. The spectra generated by tape scans are stored in the RF11 disk emulator, which is operated in an add-one-to memory mode. Up to 256 selected parameter windows can be set on either of the three parameters--(pulse height)1, (pulse height)2, and time. The stored spectra can be plotted, stored on tape or disk, and subsequently analyzed by peak-fitting programs using least-squares minimization criteria.

## Conclusion

In planning this computer system certain basic criteria were set so that the support of a wide range of experiments could be successfully achieved. The choice of separation of data acquisition and data analysis rather than a multitasking system seems to us to be a prudent choice. There is no doubt that different facilities have requirements that differ, but in this case this configuration has proven to be successful for a variety of users.

The basic criteria for this system are as follows:

1. Use of commercially built equipment whenever possible.
2. Use of commercially available, fully documented software.
3. Writing of code in a higher level language familiar to all scientists, FORTRAN. The avoidance of hardware and software specialists is achieved through active participation of scientists in the hardware and software development.
5. Existence of limited set of simple numeric commands for the users at the control console.
6. Separation of data acquisition and data analysis so as to avoid complex and high overhead multitasking systems and to guarantee trouble-free system operation.

## References


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