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THE IPNS DATA ACQUISITION SYSTEM

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ABSTRACT

The IPNS Data Acquisition System (DAS) was designed to be reliable, flexible, and easy to use. It provides unique methods of acquiring Time-of-Flight neutron scattering data and allows collection, storage, display, and analysis of very large data arrays with a minimum of user input. Data can be collected from normal detectors, linear position-sensitive detectors, and/or area detectors. The data can be corrected for time-delays and can be time-focussed before being binned. Corrections to be made to the data and selection of inputs to be summed are entirely software controlled, as are the time ranges and resolutions for each detector element. Each system can be configured to collect data into millions of channels. Maximum continuous data rates are greater than 2000 counts/sec with full corrections, or 16000 counts/sec for the simpler binning scheme used with area detectors. Live displays of the data may be made as a function of time, wavevector, wavelength, lattice spacing, or energy. In most cases the complete data analysis can be done on the DAS host computer. The IPNS DAS became operational for four neutron scattering instruments in 1981 and has since been expanded to seven instruments.

1.0 INTRODUCTION

Scientific requirements for the Data Acquisition System for IPNS neutron scattering instruments were extensively analyzed in 1978-79 before the DAS was designed. The first section below summarizes our assessment of the requirements at that time. This is followed by a section outlining the DAS design selected and detailing specific hardware and software implementations. The third section summarizes our experience with the DAS since Summer, 1981 when it became operational. In this latter section we discuss current performance levels and the extent to which the initial requirements have been met, and comment on the extent to which our initial assessment of requirements is still valid.

2.0 DESIGN REQUIREMENTS

2.1 Data Acquisition Requirements

Although physically the time-of-flight instruments vary considerably, they all involve qualitatively similar data acquisition and control requirements. Each of the instruments appears to the data acquisition system as a collection of detectors or detector elements, from which data are received concurrently. Each event detected must be identified with a space and time descriptor. The spatial descriptor corresponds to the physical location of the detector, or detector element in the case of position sensitive detectors, in the instrument. The time descriptor corresponds to the time of arrival of the event at the detector with respect to the time of arrival of the protons at the heavy metal target. The energy range and flight length needed for some instruments mandate a time descriptor with a magnitude up to 0.1 seconds, while the precision desired for calculational purposes for some instruments requires the time descriptor to resolve 1/8 microsecond time increments. Table I lists the expected data rates, histogram sizes, etc., estimated in 1978 for the various instruments then being planned for initial construction. Since not all of the instruments were then defined, the hardware and software for the DAS had to be designed with sufficient flexibility so that future expansion to include additional instruments would not require a major redesign effort. Future expansion of the number of detector elements or of the data rates in existing instruments should also be easily incorporated into the DAS. Also since only limited manpower was available to implement the DAS within the allotted time and to maintain it when it became operational, the system had to be designed with the intent of purchasing as much of the equipment as possible from commercial vendors.

2.1.1 Grouping And/or "Electronic-Time-Focussing" - The numbers derived for n, the histogram size, in Table I represent an immense amount of data for the user to handle for a single experiment. In many cases this degree of spatial resolution is not required and the user would prefer to have a considerably condensed data set with which to work. In particular, in many cases the outputs from a number of detectors could be combined after suitable manipulation, so that a single set of time channels would represent that entire group of detectors. Thus it was required that the DAS be capable of providing such suitable manipulations "on-the-fly" on the raw data to allow such "grouping" of detectors. This concept has sometimes been referred to as "electronic time-focussing". Since the grouping desired differs from instrument to instrument (see below), and may differ from experiment to experiment on a given instrument, the selected grouping scheme must be very flexible. Changing of the grouping must also be a relatively simple task. Any such grouping should not cause a degradation of the resolution as far as the variable of interest is concerned.

In the case of the powder diffractometers the desired grouping would combine detectors in such a way that events corresponding to the same d-spacing between crystalline planes in the sample would be binned in the same channel. This diffraction by the sample is governed by Bragg's law W = 2d sin THETA, where W is the neutron wavelength and THETA is one half the scattering angle, and for the time-of-flight case this reduces to

d = (h/2m) (1/L sin THETA) (t - t0)

Here L is the total source-sample-detector path length, t is the time of detection of the neutron, and t0 is the average time of emission of the neutron from the source. This grouping to combine events with the same values of d is best done before histogramming the data, as this calculation should be carried out with a high degree of precision in t if the overall resolution of the instrument is not to be degraded by the grouping process.

In the case of the chopper spectrometers, the desired grouping would combine events corresponding to the same scattered neutron energy Es. This is given by

Es = m Ls**2/2(t - t1)**2

where Ls is the sample-detector distance, t is the time of detection of the neutron, and t1 is the time the neutron was at the sample. (t1 is determined by the chopper open time and is the same for all detectors.) For some IPNS instruments, detectors are located at several values of Ls, so events with the same (t - t1)/Ls must be combined.

2.2 Other Requirements

IPNS is a "user-oriented" facility with major emphasis placed on satisfying the needs of an outside user community, many of whom are only occasionally involved in neutron scattering. Thus the DAS must be designed to interface with such "non-expert" users, and to minimize the amount of user input required to carry out routine operations. In order to support the fairly rigid scheduling inherent in a "user-oriented" facility, the DAS must be highly reliable, and must be reasonably immune to user errors. In particular, a user error or other failure on one instrument should not affect the operation of another instrument.

Display of live data is essential for each instrument if the users are to interact effectively with their experiments. Effective displays of both area-detector and non-area-detector data are also important if "non-expert" users are to be able to interpret the unfamiliar time-of-flight data. Hard-copy plotting capabilities should be readily accessible to each instrument.

It should be possible for the outside user to complete at least a preliminary data reduction, and preferrably a final data reduction, while at the IPNS facility. This is particularly important because the immense quantities of raw histogram data and the form in which the data appear in the histogram often make it difficult to ascertain the quality of the data or the appropriate course for further measurements until after the data reduction has been completed. An estimate of the computing power required to provide this analysis capability was made by scaling from previous experience with time-of-flight instruments. This estimate indicated that the analysis of data from a full complement of 12 instruments would require the equivalent of 2-3 hours of computing time on the IBM 370/195 system at the Argonne Central Computer Facility, per day of operation of the IPNS facility. Sufficient on-line disk storage must be available to handle all the data sets currently involved in analysis for each instrument. The histogram size and time/data-set data in Table I were used in estimating storage requirements. With the exception of the SCD, these requirements amount to a few Mbytes per instrument.

Requirements for control and monitoring which can be foreseen include monitoring and/or control of chopper-source phasing, driving of stepping motors to change sample or detector orientations, and monitoring and/or control of experimental environment parameters (eg - temperature, pressure, magnetic field, etc.).

3.0 IPNS DAS DESIGN AND IMPLEMENTATIONS

To fulfill the DAS requirements it was decided to provide each instrument with a number of processors dedicated to specific tasks. The tasks were divided into five main categories:

1. Data acquisition and histogramming
2. User interface and instrument control
3. Video display of data
4. Data analysis and bulk storage
5. Communication between the various processors

Figure 1 contains a block diagram of the distributed processor configuration used for the data acquisition system at IPNS. The separate subsystems are discussed in turn below.

3.1 Data Acquisition

3.1.1 CAMAC Hardware - CAMAC was chosen to provide a flexible, modular, standardized system in which to implement the special-purpose modules required to encode the data. The CAMAC system developed for the IPNS instruments is shown in block form in Figure 2. The time-of-flight discriminator modules used in the system have the common feature of interfacing to the CAMAC dataway through a First-In First-Out (FIFO) buffer memory. The function of these FIFO's is to acquire data at high instantaneous rates and to allow faster transfer of the data from the CAMAC system to the Multibus system by the use of Direct Memory Access (DMA) block transfers of the data.

In addition to the crate controller and time-of-flight discriminator module(s), two specialized modules are required in each system. These are the Polling module and the Clock module. This leaves 20 slots free for discriminator modules in each crate.

The Polling module scans the L lines from the discriminator modules within a given CAMAC crate to determine which modules contain data in their FIFO buffers. When a module is found which contains data the polling module passes an 8-bit byte to a parallel I/O port on the Multibus. This port in turn interrupts the Z8001 microcomputer and supplies it with the 8-bit byte, three bits identifying the crate and five bits indicating the module number within the crate. For some of the instruments it is necessary to have more than one CAMAC crate filled with discriminator modules. For this reason the polling module is designed to fill the role of either master or slave. As a slave unit the module will scan only its crate, while in the master mode it also scans the slave units in other crates.

Only one master clock module is used for each instrument computer system. This module generates an 8 MHz clock, which will result in a clock start time uncertainty of 125 ns, and will produce digitized times in 125 ns increments. Upon receipt of a t0 pulse (pulse indicating neutron production at the source) the module produces a 'SYNC' pulse which is used by the discriminator modules as a time digitizer reset pulse. The number of t0 pulses received while data acquisition is active are counted by a 24 bit counter. Upon command from the CAMAC controller, or from external hardware command, the clock module issues an 'INHIBIT' signal, synchronized to the t0 pulse. Upon receipt of the 'INHIBIT' signal all discriminator modules stop data acquisition. The clock module also has provisions for allowing data acquisition only within a programmable time window after each t0 pulse.

The CAMAC Time-of-Flight Discriminator Modules which are used for standard and linear position sensitive detectors produce output formats which are the same for both types of detectors, although the detector signal is digitized differently for each detector type. For the standard detectors, each discriminator module can handle inputs from 8 independent detectors. Each input has its own programmable lower discriminator level, and all 8 have a common, programmable upper discriminator level. When an analog pulse on one of the inputs falls within the discriminator levels, a 20-bit time word is combined with 3 bits of input identification, and the resulting 23 bits is loaded into a FIFO buffer in the module. The buffer can store sixteen 24-bit words. When this FIFO contains 8 data words, the module sets a CAMAC LAM indicating that the module requires service. The 24th bit in these words is used to indicate FIFO overflow. Data acquisition can be gated on or off at all modules by an 'INHIBIT' signal generated in the clock module.

The discriminator modules for linear-position-sensitive detectors produce a 20-bit time word, and 1 bit to indicate FIFO overflow. The 3-bit input identification now contains detector position information. This module also has a programmable window discriminator. In addition, it has position encoding circuitry which enables it to digitize the position information for one or two linear-position-sensitive detectors depending upon the resolution desired. The resolution is selectable to either 1 part in 4 or 1 part in 8. With the lower resolution, two detectors can be serviced, with the upper bit of the 3-bit position code indicating from which detector the data originated.

For area-position-sensitive detectors (initially present only on the SCD instrument) the role of the discriminator module is filled in part by an x-y position digitizer at the detector, in part by a time digitizer module, and in part by one or more 256 word x 16 bit commercial CAMAC FIFO modules (see Figure 2). The x-y position digitizer provides 8 bits of x and 8 bits of y position in digital form. The time digitizer module latches the x-y position data, produces a 16-bit time word, and multiplexes and strobes these into the FIFO module. The FIFO module(s) also set a CAMAC LAM when they are filled to a selected level.

3.1.2 Multibus Hardware - The MULTIBUS (Trademark of Intel Corp.) was chosen as the system bus for the data acquisition computer because of the large array of support products available for this bus structure. The data acquisition Multibus system is made up of a Multibus crate containing four boards plus memory. The four boards are:

1. A Z8001-based single board computer
2. An interface to the CAMAC controller
3. An interface to the communications processor
4. An I/O board containing both serial and parallel I/O ports

The communications interface board is discussed below as part of the PDP-11 to Multibus link. The two interface boards, along with the CAMAC modules noted above, are the only custom designed hardware in the system. Memory boards with capacities of 128 Kbytes and 512 Kbytes are used, with the amount of memory contained in each system being dependent on the instrument. Each Multibus system has at least 128 Kbytes of this RAM memory, which is used for both program and data storage.

The data acquisition computer uses a 16-bit Z8001 microprocessor. This microprocessor was chosen mainly for its ability to directly access the large amounts of memory needed for building the space-time histograms which can contain several million elements. The data acquisition computer is a Multibus compatible product built by Central Data Corporation. This computer board provides 24 memory address lines to allow addressing of up to 16 Mbytes of memory, which is sufficient for all instruments currently envisioned. It also contains a 2K word PROM monitor which on power-up is written into and executed from RAM. This monitor provides on-line debug capabilities for the data acquisition programs.

3.1.3 Software And Data Flow - The data acquisition programs for the Z8001 are written and assembled using the PDP-11 user interface computer as a program development system. The histogramming programs are basically table-driven routines to allow flexibility in the formatting of the histograms. These tables are generated by routines on the PDP-11 when the user sets up the run, and are then down loaded to the Z8001 at run time.

During a data acquisition run, the Z8001 works on histogramming the data except when the CAMAC Polling module causes an interrupt. Upon receipt of this interrupt, the Z8001 programs the CAMAC controller for a DMA transfer of the data from the FIFO in the Discriminator module requesting service to a 2K byte software-controlled circular buffer in the processor data memory. This block of data is then given a header containing the number of bytes in the block and the crate and slot number of the module from which the data was read. After this the Z8001 goes back to building histograms from this data.

Most of the instruments utilize only standard and/or linear-position-sensitive detectors. The algorithm developed for histogramming in this case emphasizes flexibility, since data-rate considerations indicate that speed is not of overriding importance. In this algorithm the fields are organized as 'time fields', each of which contains the histogram locations to hold the data from one group of detectors for one histogram. The histogram structure is controlled by four binning tables (DMAP, TTYPE, TSHIFT, TSCALE) which contain the information required by the Z8001 algorithm in order for it to properly histogram the data.

In this case the raw data stored in a block in the raw data circular buffer is organized as 24 bit words which contain 3 bits of input ID along with the time information. These 3 bits are combined with the crate and module number stored in the block header to make up the detector element identification number ID. A detector mapping table DMAP is used to determine which histograms an event with a given ID should be binned in, and for each such histogram DMAP will map ID to a memory address TSTRT for the start of the corresponding time field in histogram memory. Mapping more than one detector to the same time field results in 'grouping' of detectors.

The fundamental time coordinate is the elapsed time T in 0.125 microsecond clock cycles, which is encoded as a 20-bit number within the 24-bit raw data word. When "electronic-time-focussing" is desired, a pseudotime T* is calculated from T using the algorithm

T* = (T - CD - ED) + KSC*(T - CD - ED)/2**15

and this T* is then used in determining the mapping within this time field. The parameter CD is a constant time shift parameter, while ED is a time shift parameter which is a function of T only. The parameter KSC is found in the TSCALE table (addressed using ID) while the parameter ED is found in the TSHIFT table (addressed using a scaled T). This format for T* permits accommodation to the grouping equations simply by changing the contents of the TSCALE and TSHIFT tables.

The DMAP table also links each ID to an index ITYPE which points to a location in the TTYPE table. This table contains the descriptors which determine how each time field is organized (eg - range of pseudotime values included, parameters to determine channel widths, etc.). If ITYPE = 0 input from that detector ID will not be binned, so any given detector can be easily "turned off" by software.

In this way a completed histogram is a two-dimensional array of the form I(p,t), where "p" is the position of the detector and "t" is the time of arrival of the event at that position. This software also has the unique capability of storing a given event more than once. This is equivalent to having parallel time-of-flight analyzers. This multiple histogramming allows the data to be collected with and without scaling or shifting corrections. It also permits collection of high-resolution data over special time regions. This histogramming software is designed so that various options in time scaling and limit checking can be eliminated to allow acquisition of data at higher average rates.

A second algorithm was developed to histogram data from area-position-sensitive detectors (initially used only for the SCD). In this case the CAMAC modules encode each event as 16 time-bits and 16 position-bits. The algorithm developed for this case emphasizes histogramming speed rather than flexibility, since data rates are high and the expected uses of the data do not require wide variations in histogram mapping. This algorithm is also table-driven, but the tables used in this case are much larger and provide a direct mapping of the 16-bit raw-time word and the 16-bit raw-position word. The histogram is organized in 'position fields' rather than time fields, as this format is better matched to the data display and analysis requirements.

The 16-bit time word is used in addressing a look-up table (192 Kbytes long) which maps to the 24-bit address PSTRT for the start of the corresponding position field. The 16-bit position word is used in addressing a word look-up table (128 Kbytes long) to find the 16-bit offset from PSTRT to the channel for this event. In the initial implementation the position and time look-up tables are independent and each event can be binned in only one histogram. Also, at least initially, position mapping is taken to be uniform over the face of the detector, although this is not a fundamental requirement.

The software is designed so that both types of detectors can be handled (using both algorithms and both types of parameter tables) concurrently by the Z8001. This permits, for example, the operation of standard beam monitor detectors concurrently with an area-position-sensitive detector.

3.2 User Interface

The user interface computer is a DEC PDP 11/34 containing 256 Kbytes of memory, two RL-02 10 Mbyte disk drives, a VT-100 raster scan video terminal, and an LA-120 hard copy terminal. This computer runs under DEC's RSX 11/M multi-tasking operating system. It also contains an a direct Unibus interface to a second CAMAC controller which is used to control various devices associated with the instrument, such as stepping motors, sample changers, or shutters.

The instrument computer system configuration chosen, with the Z8001 microcomputer dedicated to data acquisition, provides a system capable of executing a variety of data-histogramming algorithms while leaving the PDP 11/34 minicomputer free to serve as a powerful and flexible interface to the user. All communication between the user and the data acquisition system takes place through the PDP-11 computer via the VT-100 terminal. The commands are executed under control of the RSX Monitor Console Routine (MCR) or a special command interpreter (PNS).

All data collection is organized around the concept of a run. All parameters defining a particular run, including the histogramming tables discussed above, are set up by the PDP-11 in a run file header, and the histogrammed data is later appended to this header to make a complete run file which contains the information necessary for subsequent data analysis. User commands have been implemented on the PDP-11 to set up histogramming tables tailored to a specific experiment; to schedule, start, and stop data acquisition for a run or a series of runs; and to print or display data or other run information in various formats on the graphics display terminal. Additional commands are available for diagnostic and maintenance purposes.

Set up of the run file headers has been kept as simple as possible consistent with the wide flexibility offered. As much of this information as possible is obtained automatically. If the method of data collection is the same as in a previous run, the previous run may be used as a "Default Run" which furnishes all information except the title and user name. Even if no "Default Run" is used to set up histogramming, default values of all input except the input numbers of the detectors to be binned are supplied. However the user has the option of selecting minimum and maximum times of interest and the resolution desired, as well as time-focussing parameters for each detector. If desired, the channel width may be doubled after a given number of channels to allow compression of the lower energy portion of the spectrum where there are not many peaks.

When a run is started, the histogramming algorithm is downloaded to the Multibus system and the tables from the selected run file are then downloaded to that system as well. The PDP-11 then issues a 'start' command to the Z8001 to initiate independent data acquisition. The layout of Multibus Memory after loading the data acquisition program and the histogramming tables is illustrated for instruments without area detectors in Fig. 3. An area of Multibus Memory has been set aside for the raw data table, and other areas have been reserved for FIFO overflows and for channel count overflows. When the count in a channel exceeds the maximum for a 16 bit word (65535) the acquisition program automatically stores the address of the overflowing channel in the overflow buffer and these channel counts are corrected in the analysis phase.

In addition to the setup of histogramming tables, the PDP-11 is also used extensively for graphics displays (see Display section below), for backing up the data to disk, for user initiated data printouts, for monitoring the progress of the data acquisition process, etc.

3.3 PDP-11 To Multibus Link

The PDP-11 to Multibus link is implemented with two boards, a Unibus Micro Controller (UMC) board from Associated Computer Consultants on the PDP-11 Unibus, and a custom Multibus interface board on each Multibus. The UMC board can control seven Multibus interfaces, thus allowing each PDP-11 computer to link with up to seven independent Multibus systems.

The UMC provides a Z80 micro-computer with compatible Z80 peripheral chips together with Unibus DMA circuitry, 32 single-byte registers accessible from the Z80 and PDP-11, and a programmable PDP-11 interrupt vector. The local Z80 bus from the UMC is extended via a flat cable to interface boards in each linked Multibus. Each Multibus interface provides a bidirectional 64 word FIFO thru which data flows asynchronously between the local Z80 bus and the Multibus, DMA control logic and addressing registers for Multibus to FIFO transfers, 2 single-byte registers accessible as I/O ports from the Z80 and Multibus, and controls to reset the Multibus and generate a low priority interrupt on the Multibus.

Each new 24-bit Multibus address is generated by hardware addition of a 24-bit increment register and a 24-bit address register. This addressing scheme allows the DMA transfer of non-contiguous data and is used, for instance, to transfer time slices through space-time descriptor organized histograms. The data path for large block transfers between Multibus and UNIBUS is, MULTIBUS to FIFO to Z80-DMA to UNIBUS, and is handled entirely in hardware. The Z80 CPU is used mainly to accept I/O parameters from the PDP-11 in order to set up MULTIBUS and UNIBUS address registers and to program the Z80-DMA. The Z80 CPU also uses shared registers and interrupts as mechanisms to handle DMA initiations and completion sequences.

Besides transferring large data blocks directly between the Unibus and Multibus the communication processor system also passes short command blocks to the Z8001 from PDP-11 tasks. The command and the parameters needed to complete the command are located in the Subfunction byte and 6 Parameter words which are included in every PDP-11 RSX I/O request (i.e. - the QIO executive directive). The Z80 passes these command blocks to fixed Multibus locations and interrupts the Z8001 at a low priority. The PDP-11 I/O completion then awaits the interpretation and implementation of this command block by the Z8001. The communication processor can handle up to 32 separate PDP-11 I/O channels. Since the PDP-11 needs only one channel per Multibus for sending a command block, all Multibus systems attached to the PDP-11 may be executing commands simultaneously.

3.4 Display

The display processor is a VS11 bit slice processor produced by the Computer Special systems group of DEC, which provides for raster graphics display with a resolution of 512 x 512 pixels with up to 16 colors or intensities.

Instructions and graphic data are placed in a "display file" in the PDP-11 memory, where they are accessed in a DMA operation by the VS11 image processor. Programming of graphic displays consists of setting up the appropriate display file which can be updated concurrently with its access by the VS11 image processor. The VS11 operation is synchronized to the PDP-11 software, where necessary, by the appropriate use of "start" and "stop" commands to the VS11. Otherwise the VS11 and PDP-11 operations are asynchronous.

The existence of the "point" and "vector" graphic modes makes it relatively simple to interface the VS11 to standard "pen-plotting" graphics software packages. We have interfaced the VS11 instruction set to such a pen-plotting software graphics package, and this package is used for display of histogram files stored on disk. However "live" data updating is programmed directly with the VS11 instruction set to achieve greater plotting speed. The "bitmap" graphic plotting mode is used for "density plot" representations of two-dimensional slices through histograms.

The display of "live" histogram data being accumulated in the Multibus memory involves the concurrent and asynchronous operation of the four front end processors. The PDP-11 determines, on the basis of user input, which portion of the histogram is to be displayed. The communication processor supervises the transferring of the histogram data to a static common region in the PDP-11 memory several times per second. Continuous-loop applications software operates on the data in this static common, performing scaling, change of units, etc., and then places this data in proper format in a display file. The display processor in the VS11 cycles through the display file and converts the data to pixel information and stores it in its image memory. This software produces rapid display updates which provide a good sense of the "live" nature of the data, as it is being histogrammed by the Z8001.

3.5 Data Analysis

A DEC VAX 11/780 is used for complex data analysis and shared I/O with all instrument systems. This data analysis computer includes 2 Mbytes of RAM memory, a Floating Point Accelerator, a 516 Mbyte disk (RP07), a 67 Mbyte disk (RM03), two 10 Mbyte (RL02) disks, a 800/1600 bpi magnetic tape drive, a Versatec printer-plotter, a 300 lpm Printronix line printer, modems, a number of VT-100 display terminals, and a VS11 graphics display processor with a color monitor.

This data analysis computer is meant to receive data from the various instrument computers via the communication interface or by transferring RL02 disk packs from the front-end computers. The data is then either stored or analyzed by routines provided by the user. After reduction the data can be plotted and/or printed by the various output devices connected to the VAX or it can be shipped back to the instrument system for display or further manipulation.

3.6 PDP 11/34-VAX Link

A serial high speed synchronous link is being developed between the PDP-11 front end computers and the VAX. Its main function will be to move large data files between the two processors. Its operation is not essential to data acquisition but will be useful in transferring data to the VAX for analysis. This transport is currently accomplished by moving the RL02 data disk from the front-end computer to the VAX. A low-speed serial link allows users to call up the VAX and log on to their front-end computer to check on the status of their experiment. The hardware for the high-speed serial link is in place and the software is now under development.

4.0 PERFORMANCE SUMMARY

The IPNS DAS became operational for four of the first five instruments in Summer, 1981. Construction of the fifth of the proposed initial instruments was completed in 1982, and it and two other instruments have been added to the DAS since it first became operational. Our experience with some of the various aspects of the system is outlined in the separate sections below.

4.1 Expansion

During 1981-82, the software on the PDP-11 computers and in the PDP-11 to Multibus interface computer (Z80) was modified to allow each PDP-11 computer to serve more than one instrument. In this implementation, each instrument still has its own independent CAMAC-Multibus Data Acquisition system, but shares the user interface, disk backup, graphics display, and link to host, with one or more additional instruments. In this manner the original five PDP-11 computer systems and VS11 graphics systems now support seven instruments, with an eighth soon to be added. The ease with which this expansion was performed indicates that the goals of flexibility and expandability have been well met. However, although this sharing of PDP-11 computers has resulted in significant cost savings, it has somewhat compromized the initial goal of complete independence of instruments. It is thus not as satisfactory a means of expansion as would be a simple expansion by including more of the independent complete instrument computer systems.

4.2 Data Rates

The initially established goals for instantaneous data rates have been achieved. The pulse-pair resolution for pulses in the same discriminator module is approximately 2 microseconds, while there is no interference whatsoever between pulses in different discriminator modules. This seems to be quite adequate for all data acquisition situations seen to date. However, for the area detectors where position encoding is done as part of the detector rather than as part of the DAS, pulse-pair resolution is of the order of 7 microseconds, and this does cause a dead-time problem.

The initially established goals for time-averaged data rates have been exceeded. The DAS can handle rates as high as 3000 events per second for non-area-detector instruments, and rates of up to 16,000 events per second for area-detector instruments. This time-averaged rate has so far proved adequate for area-detectors. However, in the case of non-area-detector instruments the users immediately found it to be "essential" to make full use of the very large time-of-flight range permitted by the system. This has caused the data rates from these instruments (particularly powder diffractometers) to be much higher than was anticipated on the basis of previous experience with similar earlier instruments (which were typically restricted to under 10,000 channels total for data). Data rates for these instruments are thus pressing against the limits imposed by the DAS. To alleviate this problem, a faster single-board-computer based on the Z8001 microprocessor is being designed. The use of multiple Z8001 processors on each Multibus is another possibility which was included in the original system architecture, and this is contemplated as a possible longer-term solution. With both these improvements a factor of ten increase in time-averaged data rate should be achievable while still using the same flexible histogramming algorithm.

4.3 Histogram Sizes

The non-area-detector instruments currently have approximately 150 detectors each. In the initial calibration and testing of these instruments extensive use was made of the ability to concurrently collect and histogram data from each detector separately. The multiple-histogram option was also used extensively in this calibration/testing phase, and has been used to a lesser extent in more recent applications. Histograms (or multiple histograms) in excess of 200,000 channels have been collected on some of the non-area-detector instruments. (Multibus memory boards have on occasion been shifted between instruments to allow larger-than-originally-anticipated histograms. This is a simple process requiring only a few minutes.) In routine operation these instruments typically use 20,000 to 100,000 channels per run. The Single Crystal Diffractometer, which uses an area-detector, routinely collects histograms of about 800,000 channels.

4.4 Electronic Time-Focussing

This concept has worked extremely well. The flexibility inherent in the use of the table-driven focussing algorithm was most vividly demonstrated when the chopper was removed from one of the chopper spectrometers and a time-focussed powder diffraction spectrum was collected in that instrument from the same sample that was used in the inelastic scattering measurements. This required only the setup of a new run with the proper focussing parameters. In other tests on the powder diffractometers, detector banks at various angles (including angles down to about 15 degrees) have been focussed with no difficulty.

4.5 Display

The VS11 display has worked very well for our purposes. Especially important has been the speed of this display, which makes possible "live" updates of 4000 point histograms. Equally, if not more, important has been the density plotting capability which has been extremely useful for representing area-detector data.

4.6 Data Analysis

The presence and availability of the VAX host computer as part of the DAS has been extremely important, especially insofar as the experiments for outside users are concerned. Extensive data analysis software for the various instruments has veen developed for the VAX by the Instrument Scientists, and this has enabled outside users to begin data analysis immediately after they have completed data acquisition, and to leave Argonne with data that have already been at least partially analyzed. This computer is quite heavily used, although the CPU is not yet saturated. It appears that our initial estimate that this computer would be nearly saturated when a full complement of approximately 12 instruments was operational at IPNS is still valid.

Table 1

Instrument[a]	GPPD	SEPD	SCD	LRMECS	HRMECS
Detectors[b]					
SD	~160	~120	2	~150	~200
LPSD(Res)	~20(8)			~100(4)	~200(4)
APSD(Res)			1(256x256)		
n_d	~320	~120	~65000	~550	~1000
n_t [c]	8000	8000	256	500	1000
$n = n_d * n_t$	2.6M	1M	16M	0.3M	1M
$I^{tot}_{time\text{-}avg}$ (cts/sec)[c]	~1500	~1000	~20000	~3000	~1000
$I^{tot}_{instantaneous}$ (cts/sec)[c]	$\sim10^5$	$\sim10^5$	$\sim10^6$	$\sim10^6$	$\sim10^5$
Typical time[d] to obtain one histogram	1 day	1 day	4 hrs.	5 days	10 days

[a] GPPD = General Purpose Powder Diffractometer; SEPD = Special Environment Powder Diffractometer; SCD = Single Crystal Diffractometer; LRMECS = Low Resolution Medium Energy Chopper Spectrometer; HRMECS = High Resolution Medium Energy Chopper Spectrometer.

[b] SD = Standard ^{3}He-filled gas proportional counters; SPSD = ^{3}He filled linear position-sensitive gas proportional counters; APSD = area position-sensitive detector (^{3}He proportional counter or scintillation counter); Res = number of detector elements per detector.

[c] Worst case estimate.

[d] Estimated from experience - includes experiment setup time.

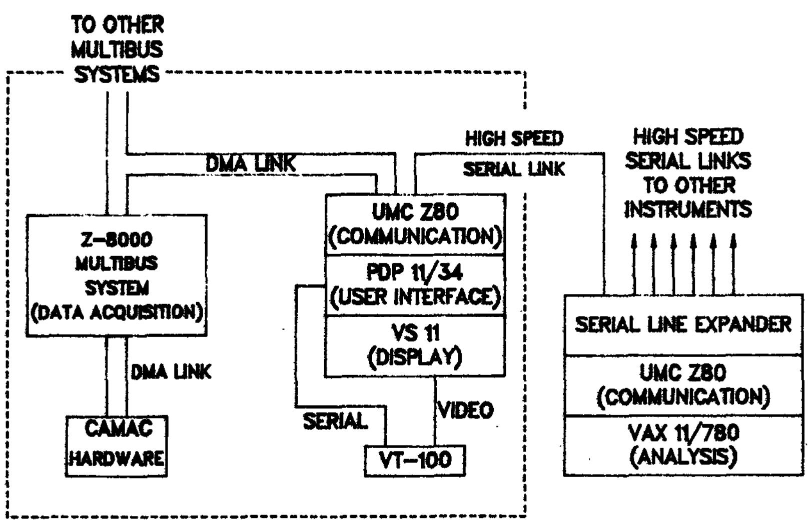

Fig. 1. A block diagram showing one instrument computer system (within dotted lines) and its link to the analysis computer.

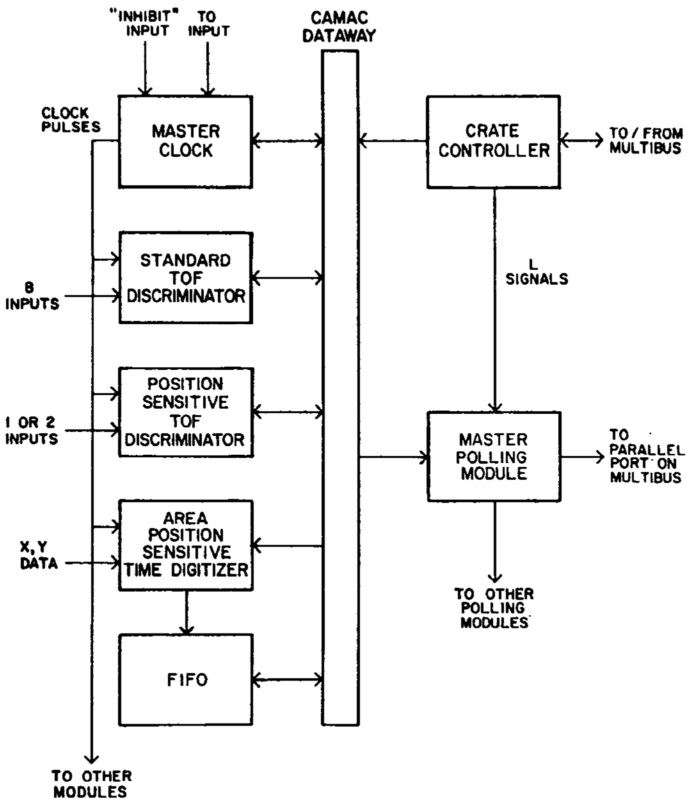

Fig. 2

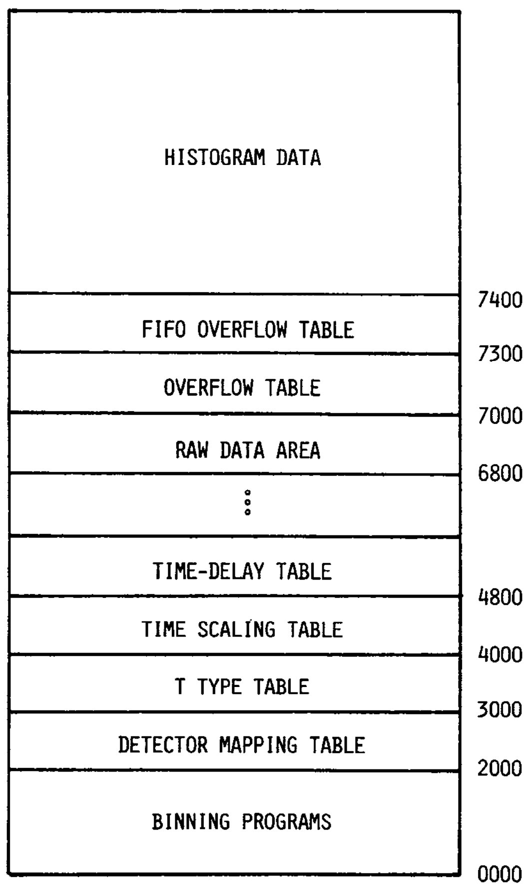

Fig. 3

Multibus memory map.