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THE DATA ACQUISITION SYSTEM FOR THE NEUTRON SCATTERING INSTRUMENTS AT THE INTENSE PULSED NEUTRON SOURCE

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Summary

The Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory is a major new user-oriented facility which is now coming on line for basic research in neutron scattering and neutron radiation damage. This paper describes the data-acquisition system which will handle data acquisition and instrument control for the time-of-flight neutron-scattering instruments at IPNS. This discussion covers the scientific and operational requirements for this system, and the system architecture that was chosen to satisfy these requirements. It also provides an overview of the current system implementation including brief descriptions of the hardware and software which have been developed.

Introduction

Neutron Scattering

Slow neutrons have energies ranging from about 0.1 meV to about 1000 meV (1 mev = 0.001 eV), which span most of the fundamental excitation energies in condensed matter. Furthermore, they have de Broglie wavelengths of roughly 0.3 to 30Å, which span the relevant microscopic structural dimensions in most condensed matter systems. These and other unique properties of slow neutrons have made slow neutron scattering a prominent and powerful probe for the study of a wide variety of condensed matter phenomena.

In general, neutron scattering instruments are designed so that the intensity of scattered neutrons can be measured as a function of the wavevectors $\vec{k} = m\vec{v}/\hbar$ of both the incident and scattered neutrons (Here m is the neutron mass, $\vec{v}$ its velocity, and $\hbar$ is Planck's constant.) This scattered intensity $I(\vec{k}_i,\vec{k}_s)$ is directly related to the differential scattering cross-section $\partial^2\sigma/\partial\Omega\partial E$.

$$I(\vec{k}_i, \vec{k}_s) \approx \phi(k_i)\, N \frac{\partial^2\sigma}{\partial\Omega\partial E}\, \delta\Omega_s\, \delta E_s\, e_d \qquad (1)$$

where $\phi(k_i)$ is the time-averaged flux of neutrons with wavevector near k_i incident on the sample, N is the number of scattering units in the sample, $\delta\Omega_s$ and δE_s are the solid angle range and energy range over which the scattered neutrons were sampled to produce the measured $I(\vec{k}_i, \vec{k}_s)$, and e_d is the detection efficiency. The differential scattering cross-section contains the microscopic structural and/or dynamic information of interest. This microscopic information is usually expressed as a function of the momentum $\hbar\vec{Q}$ and the energy E transferred to the sample by the neutron.

$$\hbar\vec{Q} = \hbar(\vec{k}_i - \vec{k}_s) = m(\vec{v}_i - \vec{v}_s) \qquad (2)$$

$$E = E_i - E_s = \hbar^2(k_i^2 - k_s^2)/2m \qquad (3)$$

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Neutron Scattering Instruments at the Intense Pulsed Neutron Source

The Intense Pulsed Neutron Source (IPNS) began operating at Argonne National Laboratory in May, 1981. IPNS is a 'new generation' source of slow neutrons for neutron scattering and of fast neutrons for neutron radiation damage studies. In the past, neutrons for these purposes have been obtained from research reactors. However, IPNS (as well as several other 'new generation' sources under construction or in recent operation) is an accelerator - based neutron source, in which pulses of protons are accelerated to high energies and directed to a heavy-metal target where they produce pulses of fast neutrons by the spallation process. For neutron scattering, these fast neutrons are moderated by small hydrogeneous moderators to provide slow neutrons in pulses of short duration (roughly 3-100 microseconds, depending on neutron energy) at a repetition rate of 30 Hz.

The pulsed nature of this source means that the neutrons are produced in a manner ideally suited to the measurement of their velocities $\vec{v}$ (and hence of their wavevectors $\vec{k}$) by neutron time-of-flight techniques. Thus all the neutron scattering instruments at IPNS are designed to utilize neutron time-of-flight techniques, and this has dictated many features of the data acquisition system designed to handle these instruments. Figure 1 shows schematically the types of neutron scattering instruments built for IPNS. Specific data acquisition requirements of these instruments are discussed in the following section.

Most neutron scattering facilities in the U.S. are utilized primarily by in-house groups of scientists most of whom spend full time on neutron scattering research. However IPNS has from the beginning been intended as 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. This has placed additional requirements on the data analysis capabilities and on the reliability and ease-of-use of the data acquisition system for the neutron scattering instruments.

Figure 2 shows an overall layout of the IPNS facility including the initial complement of neutron scattering instruments. From the Figure it is evident that the IPNS facility provides 12 horizontal beams for neutron scattering instruments, so the data acquisition system was required to be expandable to accomodate 12-15 instruments, many of which have not yet been defined.

Data Acquisition System Requirements

In addition to the obvious general requirements of reliability, non-interaction between instruments, flexibility, and ease-of-operation, a number of specific requirements were dictated by the nature of the neutron scattering instruments and by the operation of the facility in a user-oriented mode. These are outlined below.

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Data Acquisition Requirements

General. Although the various time-of-flight neutron scattering instruments indicated in Fig. 1 are physically quite different, when considered from the point-of-view of data acquisition they are all very similar. Each of the instruments appears to the data acquisition system as a collection of detectors, or separate elements of one or more position-sensitive detectors, from which data are collected concurrently. For each detector or detector element, the detected neutrons result in detector pulses, each of which must be identified with a digitized spatial descriptor x (detector or detector element in which the event occurred) and a digitized time descriptor t (measured relative to the source pulse time for example). The data acquisition system must then bin these events in a two-dimensional histogram of size $n=n_d*n_t$ for each instrument, where n_d is the number of detectors and/or detector elements in the instrument and n_t is the average number of time channels required for each detector element.

Specific Instrument Parameters. Table I lists the initial complement of instruments to be attached to the IPNS data acquisition system and indicates the number and type of detectors used by each. Table I also indicates the maximum number of time channels required per detector (or group of detectors - see below) and provides an estimate of the time-per histogram and the maximum overall peak and time-averaged data rates expected at each instrument. (These latter quantities were calculated using Eq. 1 with estimated maximum sample scattering cross-sections and using realistic instrument and ultimate-source-strength parameters. When available, experience with prototype instruments was also factored into these estimates.)

Grouping of Detectors. 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.

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 $\lambda = 2d \sin\theta$, where λ is the neutron wavelength and θ is one half the scattering angle, and for the time-of-flight case this reduces to

$$d = (h/2m)(1/L \sin\theta)(t-t_o) \qquad (4)$$

Here L is the total source-sample-detector path length, t is the time of detection of the neutron, and t_o is the average time of emission of the neutron from the source. (t_o is itself a slowly varying function of λ and hence of t.) This grouping to combine events with the same values of d is best done before histogramming the data, as the calculation in Eq. 4 should be carried out with a high degree of precision in t if the overall instrument resolution 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 E_s. This is given by

$$E_s = m L_s^2/2(t-t_1)^2 \qquad (5)$$

where L_s is the sample - detector distance, t is the time of detection of the neutron, and t_1 is the time the neutron was at the sample. (t_1 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 L_s, so events with the same $(t-t_1)/L_s$ which must be combined.

Since the grouping desired differs from instrument to instrument, 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.

Display Requirements

Display of live data is essential for each instrument if the users are to interact effectively with their experiments. Minimum required live display capabilities include simple histogram displays of selected portions of the data histogram as it is being collected, and x-y density plots of selected portions of the x-y-t histogram for the area detector on the single crystal diffractometer. Similar graphic capabilities must also be available for display of stored data and for data in various stages of analysis. Hard-copy plotting capabilities should be readily accessible to each instrument.

Data Manipulation and Analysis Requirements

During Experiment. The user must be able to apply simple corrections (eg - normalization, background subtraction, unit conversions, etc.) to the raw data histograms before or after collection of the histograms is complete. The user should be able to display these results and should be able to compare graphically all or part of the raw or corrected histograms with spectra derived from previous measurements or from calculations. Such manipulations should not interfere with data acquisition.

After Data Collection is Complete. All the manipulation features discussed above should be available at this stage as well. In addition, it should be possible for the 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. Data reductions generally include background subtractions, normalizations, unit conversions, and frequently also include least squares fits to complicated models and/or extensive calculations of extraneous effects such as multiple scattering.

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 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.

Instrument Control and Monitoring Requirements

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.) Control and monitoring operations should not interfere with data acquisition except when the monitored variables indicate that shutdown of data acquisition is appropriate. It is expected that control and monitoring requirements will expand with time, and the system must be able to accommodate this expanson with a minimum of disruption and expense.

Data Storage Requirements

Three categories of data storage are envisioned. These are temporary storage during the experiment, short-term storage (~30 days) immediately following the experiment, and long-term archival storage. Temporary storage requirements include the rapid access storage used to collect the histogram, and file storage of the data sets (eg-backround, normalization, etc.) needed for the manipulations discussed above plus some back-up data sets and some earlier data sets for comparison. Short-term storage includes the on-line file storage required during the data analysis stage. This should be sufficient to hold all the new histogram data sets, backround and normalization data etc., for about 30 days, as well as a number of analyzed or partially analyzed data sets. Long-term archival storage of raw histogram data sets would be expected to be on magnetic tape or other archival medium.

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.

Data Transfer Requirements

At the minimum, magnetic tape facilities must be provided to allow users a means to take their data home with them and to bring in analysis programs.

Hardware Implementation

System Architecture

In order to meet the requirements of reliability, non-interaction between instruments, and large computing power, and to provide each instrument with access to data transfer, hard copy, and mass storage facilities, a "star" configuration (see Figure 3) was selected for the data acquisition system. This section followed a detailed design study.[1] In this configuration each system has its own "instrument computer system" to handle the data acquisition and control, graphic display, and simple data manipulations during the experiments. Each of these instrument systems is linked via a high-speed data transfer link to a single central "host computer system" which provides the computing power necessary for data analysis. Expensive mass storage, data transfer, and display peripherals are located in the host system, where they are accessible to all instruments.

To improve the overall system reliability each instrument system is capable of standalone operation. Furthermore, in order to provide the large address space required to build histograms of the size indicated in Table I and to minimize interference between data acquisition and other functions of the instrument system, each instrument system is equipped with separate histogram memory and with a microcomputer with a large address space, both of which are dedicated to data acquisition. The remainder of the instrument system functions are handled by a minicomputer which also supervises the actions of the data acquisition microcomputer and has access to the histogram memory.

The major procurement for the data acquisition system consists of the host computer and five instrument minicomputers. These were required to be compatible with one another in addition to meeting all the other requirements set forth above. A competitive bidding process led to the selection of a DEC VAX 11/780 computer as the host with DEC PDP 11/34A computers as the instrument minicomputers. Specific configurations for these computers and for the other components of the instrument systems are detailed below.

Instrument Systems

Each instrument system can be roughly separated into three parts: a CAMAC system, a MULTIBUS system, and a PDP 11/34A system. These systems and the interfaces between them are discussed in turn below.

CAMAC System. 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 4. The data 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 two specialized modules are required in each system. These are the Polling module and the Clock module. This leaves 20 slots free for data discriminator modules in each crate.

Polling Module. The polling module scans the L lines from the data acquisition 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 to a parallel I/O port on the MULTIBUS an eight bit word. This port in turn interrupts the Z8001 microcomputer and supplies it with the 8 bit word, 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 data acquisition modules. For this reason the polling module is designed to fill the role of either a 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.

Master Clock Module. 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 t_o 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 t_o 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 t_0 pulses. Upon receipt of the 'INHIBIT' signal all modules stop data acquisition. The clock module also has provision for allowing data acquisition only within a programmable time window after each t_0 pulse.

CAMAC-Time-of-Flight Discriminators. These modules, which are used for standard and linear-position 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 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. Each crate can hold 20 such modules (160 detectors), so some instruments require more than one CAMAC crate.

The discriminators for linear-position-sensitive detectors produce a 20 bit time word, and one 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 Fig 4). 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.

CAMAC-MULTIBUS Interface. The interface between the CAMAC and MULTIBUS systems consists of a commercial CAMAC crate controller, modified to allow the polling module access to the L lines and connected to a custom interface module in the MULTIBUS system. This interface provides for high-rate block transfers of data from the CAMAC FIFO's to the memory in the MULTIBUS system, and also allows programmed transfers of control information to modules in the CAMAC system. Each interface module in the MULTIBUS system can be connected to as many as 8 CAMAC crate controllers.

MULTIBUS System. MULTIBUS is a IEEE standard system bus. In the IPNS data acquisition system the MULTIBUS links the data histogramming microcomputer, the random access memory (RAM) in which the histogram is built, and the interfaces to the CAMAC and PDP 11/34A systems. The MULTIBUS was selected over other potential bus structures primarily because of the timely commercial availability of the necessary modules for this bus.

Figure 5 is a block diagram of the basic IPNS MULTIBUS system. This system consists of a Central Data Corporation Z8001 microcomputer board and enough RAM boards to supply the required histogram and program memory. It also houses a serial-parallel I/O board used for program development and system maintenance, as well as for the input from the CAMAC polling modules and the custom modules which are parts of the MULTIBUS-CAMAC interface (see above) and the MULTIBUS-PDP 11/34A interface (see below).

The microcomputer receives raw space-time data from the data acquisition modules via the CAMAC Controller and performs logical and arithmetic transformations on the raw data as required by each instrument. The processed raw data is then histogrammed in the RAM. The microcomputer will also carry out simple control functions on the CAMAC data collection instrumentation such as: START, STOP, INHIBIT DATA COLLECTION; SET LOWER LEVEL DISCRIMINATION, etc.

The semiconductor RAM used to store the space-time histograms is implemented on MULTIBUS compatible boards (128 kbyte or 512 kbyte per board) available from several vendors. The single board microcomputer is capable of directly addressing 8 Mbytes of memory on the MULTIBUS, and with memory management hardware the address space can be extended to 16 Mbytes, which will handle all the histogram requirements envisioned.

MULTIBUS-PDP 11/34A Interface. All transfer of data between the MULTIBUS and PDP 11/34A are handled on a DMA basis. The hardware consists of a commercial interface (Associated Computer Consultants UMC-Z80) located in the UNIBUS, connected to a custom interface board located in the MULTIBUS.

The interface to the MULTIBUS enables the PDP 11 to:

1. read and write MULTIBUS memory directly in byte, word, or longword context while allowing the memory increment size between successive transfers to be programmed, thus allowing non-contiguous data transfers to/from MULTIBUS memory.

2. issue two levels of interrupts to the Z8001 microcomputer in the MULTIBUS. These are Interrupt Level 0 and NON-MASKABLE-INTERRUPT.

3. issue a RESET to the MULTIBUS.

The ability of the hardware and the PDP 11 software driver to multiplex I/O requests from the PDP 11 enable the interface to appear as 12 separate I/O channels. Presently only three of these channels are implemented. One supports general purpose MULTIBUS communication, another supports I/O transfers related to histogram display functions, and the third supports full duplex synchronous data transfers to the HOST computer.

PDP 11/34A System. Figure 6 shows the PDP 11/34A system configuration. Each such system consists of a DEC PDP 11/34A minicomputer with hardware floating point, 256 kbyte solid-state memory, dual RL02 10 Mbyte cartridge disks, and a DEC LA120 hard-copy

terminal. This system uses the RSX-11M operating system. Each system also includes a DEC VS11 raster graphics system (512 x 512 resolution) utilizing a DEC VT100 as monitor and/or video terminal. Also included with each PDP 11/34A system is a CAMAC crate interfaced to the PDP 11 through a CAMAC controller. This CAMAC crate and controller are used for control and monitoring instrumentation.

PDP 11 - Host Data Link

At the PDP-11 the same commercial interface (UMC-Z80) used as part of the MULTIBUS-PDP 11/34 INTERFACE also provides the hardware to support high rate synchronous serial data transfers to the Host computer using the SDLC protocol. At the VAX Host computer, another commercial product (SLEB) is used which also supports the high rate SDLC serial communication protocol. These commercial products implement at each end of the communication link from each PDP-11 to the VAX a Z80 microcomputer, 2 Kbytes of memory, and a Z80 SIO communication chip dedicated to transferring data over the link. The data will be transferred from internal Z80 memory to either PDP-11 or VAX memory on a DMA basis.

The hardware is presently in place and software drivers are being written. Initial emphasis will be placed on supporting high rate (500 Kbaud) transfer of large data sets between the PDP-11 and the VAX.

Host System

Figure 7 shows the initially implemented Host system configuration. This system presently consists of a DEC VAX 11/780 computer with Floating-Point Accelerator, 1 Mbyte of solid-state memory, one RM03 67 Mbyte disk drive, one RL02 10 Mbyte cartridge disk drive, one TU77 800/1600 bpi-125 ips tape drive, one LA120 hard copy terminal, and three VT100 video terminals. This system uses the VAX/VMS operating system. The system also includes a DEC VS11 raster grahics system with a Hitachi color monitor, a VERSATEC 1200A electrostatic printer/plotter, modems, and a Printronix line printer. It is expected that disk capacity on the Host system will be expanded to meet user needs.

Software Implementation

Instrument Computer Software Organization

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 11/34A minicomputer free to serve as a powerful and flexible interface to the user. The philosophy has thus been to limit Z8001 software to the data acquisition algorithms themselves plus a few additional data-acquisition-related functions, and to implement all other software on the PDP-11/34A. This other software includes programs for interactive setup of histogramming parameters, downloading programs and parameters to the Z8001, initiation and monitoring of data acquisition, control of instrument parameters (eg - angle settings, etc.), disk backup of histogram data, display of live or stored data, communication with the Host computer, and data manipulations including conversion of units, etc.

Concepts. The software for both the Z8001's and the PDP 11/34A's is organized around the concepts of 'Histograms', 'Histogram Fields', and 'Runs'.

The Z8001 microcomputer receives each event as 32 bits of position and time information. It is the job of the microcomputer to map this position and time information to a memory address and to increment the contents of that address. This process is referred to as 'binning' the raw data into 'histogram' representations of the data. Each event may contribute at most once to any one histogram. However the microcomputer can repeat the binning process several times for each event, thus concurrently producing several different histogram representations of the same raw data set. These different histograms are identified by a histogram index IH.

Within the histogram the data is organized into 'fields', each of which consists of contiguous memory locations. The first two words of a field are reserved for the total number of counts in the field, which provides a check on data integrity.

A 'Run' is defined as a data acquisition operation of the system with a single distinct set of instrument and histogramming parameters. Each separate Run is assigned a 'Run Number'. All the parameters used to set up a Run (parameters controlling data histogram organization, sample and instrument parameters, etc.), other pertinent parameters (time of Run setup, time of data acquisition start, etc.), and the raw histogram data collected during that Run are all gathered into one 'Run File' identified with that Run Number, with a different Run File being used for each Run.

Histogramming Algorithms and Parameter Tables. It is possible to satisfy the requirements of four of the first five instruments with a single, table - driven histogramming algorithm. These four instruments (GPPD, SEPD, LRMECS, HRMECS) utilize only standard and/or linear-position-sensitive detectors. The algorithm developed for 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. (See Fig 8a.) 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 fundamental position coordinate is the detector element identification number ID, which is encoded (see above) as an 11-bit number within the 32-bit data word corresponding to an event. 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 32-bit data word. When desired, a pseudotime T* is calculated from T using the algorithm

$$T^* = (T - CD - ED) + KSC^*(T - CD - ED)/2^{**}15. \qquad (6)$$

and this T* is then used in determining the mapping within the 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

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 (Eqs. 4 or 5) 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.

These tables are set up by programs in the 11/34A which interact conversationally with the user. After being set up, the tables are written into the header region of the run file for this particular run, where they become a permanent part of the data set for this run. When this run is started, the histogramming algorithm is downloaded to the MULTIBUS system and the tables from this run file are then downloaded to that system as well. The 11/34A then issues a 'start' command to the Z8001 to initiate independent data acquisition.

A second algorithm was developed to histogram data from area-position-sensitive detectors (initially used only for the SCD). 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. This organization is shown in Fig 8b.

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.

Set up of the parameters for the histogramming tables is done with programs on the 11/34A. However, because of the size of the tables, rather than storing the tables themselves in the Run File, only the parameters (eg - position resolution, time resolution, minimum and maximum times, etc.) which define the tables are stored in the Run File. At run time the Z8001 uses these parameters to generate the Tables, which are then stored in the MULTIBUS RAM.

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 the area-position-sensitive detector on the SCD instrument.

Host Software

All data analysis software on the VAX 11/780 system is the responsibility of the users. IPNS provides and maintains software on this system for interfacing with Run Files, communications with the instrument systems and for display.

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]	~10^5	~10^5	~10^6	~10^6	~10^5
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.

Figure Captions

Fig. 1 Schematic representation of time-of-flight neutron scattering instruments. (a) Powder diffractometer. Neutrons are elastically scattered by the sample. Neutron wavevector magnitudes and directions are determined respectively by the source-sample-detector flight times and by the scattering angle to the specific detector. (b) Chopper Spectrometer. A specific incident neutron energy is selected by the relative phasing of the source pulse and the chopper-open time. Scattered neutron energies and directions are determined by the chopper-sample-detector flight times and by the detector location. (c) Single Crystal Diffractometer. This instrument is similar to a powder diffractometer, except that an area-position-sensitive detector is used for precise determination of the directions of wavevectors of scattered neutrons. Detectors for instrument types (a) and (b) may be linear-position-sensitive detectors if warranted by the requirements for spatial resolution normal to the nominal scattering plane.

Fig. 2 Intense Pulsed Neutron Source (IPNS) Facility. All instrument and Host computer systems are housed in the environmentally controlled areas marked INST COMP and HOST COMP. The area marked RADEFF houses equipment for the Radiation Effects Facility which is also part of IPNS. Instruments SAD and CAS use previously existing data acquisition systems.

Fig. 3 Data acquisition system "star" architecture, showing specific hardware implementation.

Fig. 4 CAMAC data collection portion of Instrument Computer System.

Fig. 5 MULTIBUS portion of Instrument Computer System.

Fig. 6 PDP 11/34A configuration in Instrument Computer System.

Fig. 7 VAX 11/780 Host Computer initial configuration.

Fig. 8 Schematic representation of the position and time mappings used in generating histograms. (a) Algorithm for standard and linear-position-sensitive detectors. Note the flexibility in channel widths, and in range of t^* values histogrammed. Note also the possibility of collecting more than one histogram from the same events. (b) Algorithm for area-position-sensitive detectors.

References

1. R.T. Daly, J.R. Haumann, M.R. Kraimer, F.R. Lenkszus, W.P. Lidinsky, C.B. Morgan, L.L. Rutledge, P.E. Rynes, and J.W. Tippie. IEEE Transactions on Nuclear Science NS-26, 4554 (1979).

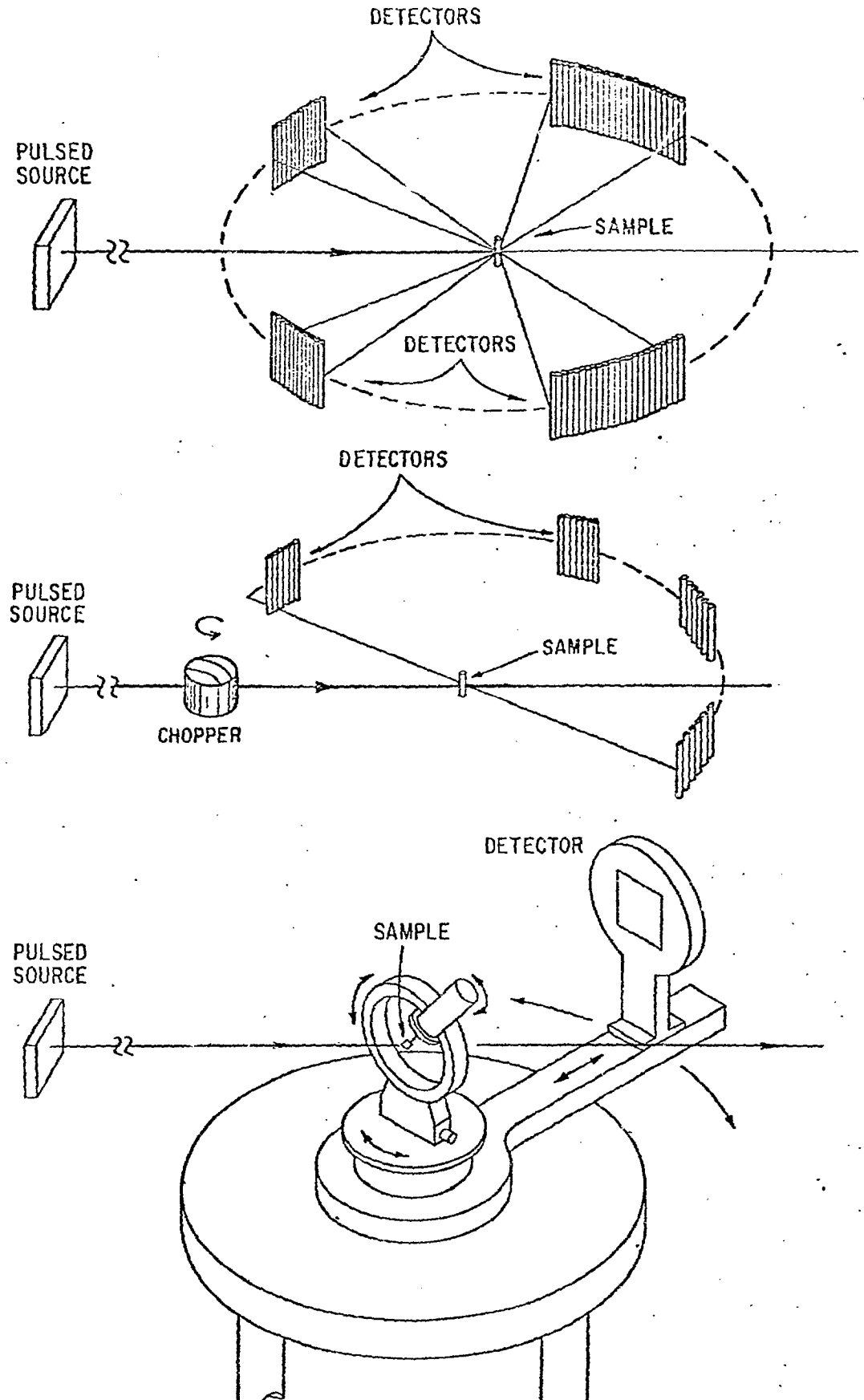

DETECTORS
PULSED SOURCE
SAMPLE
DETECTORS
DETECTORS
PULSED SOURCE
SAMPLE
CHOPPER
DETECTOR
SAMPLE
PULSED SOURCE

Figure 1

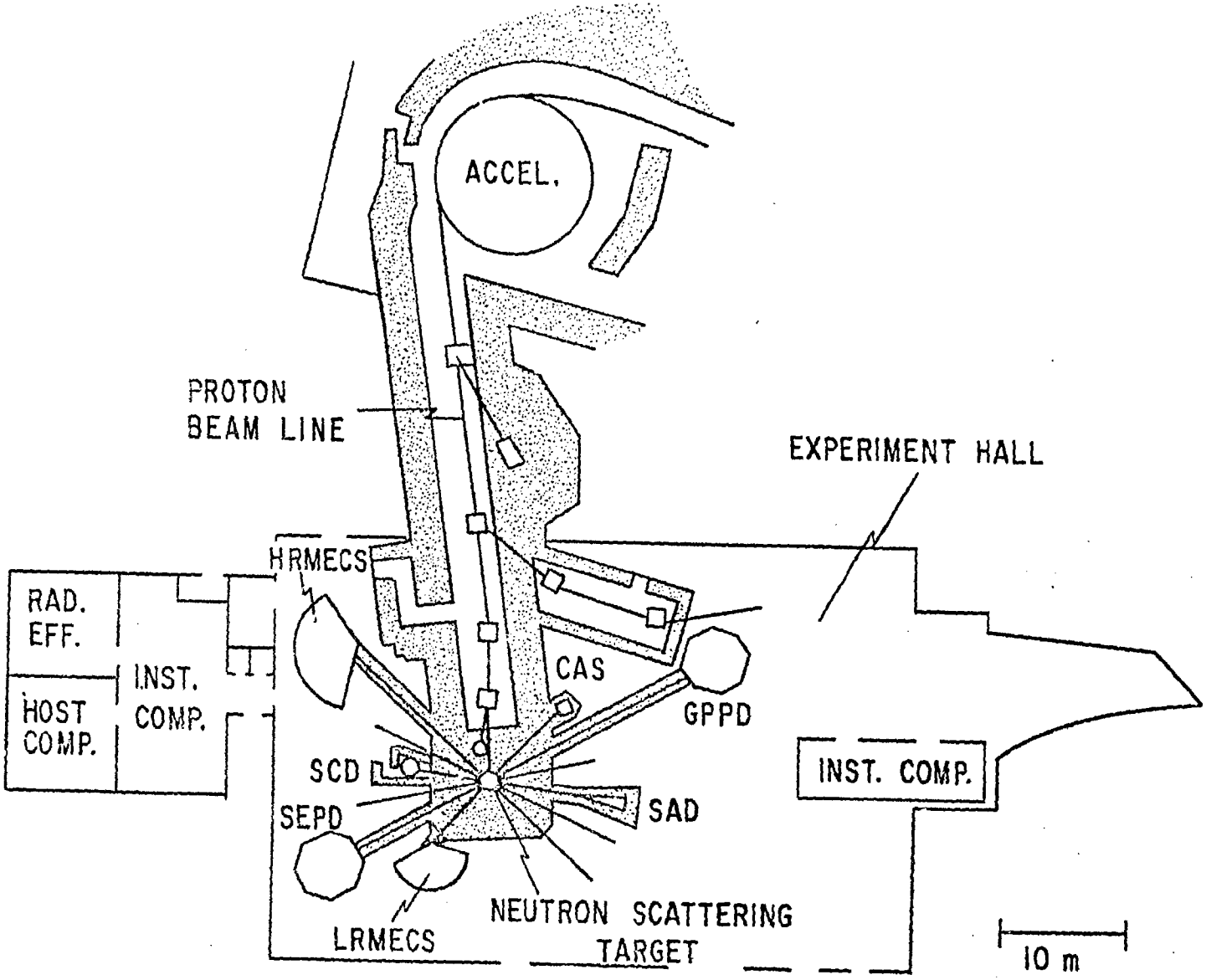

ACCEL.
PROTON
BEAM LINE
EXPERIMENT HALL
HRMECS
RAD.
EFF.
HOST
COMP.
INST.
COMP.
CAS
GPPD
SCD
SEPD
SAD
INST. COMP.
LRMECS
NEUTRON SCATTERING
TARGET
10 m

Figure 2

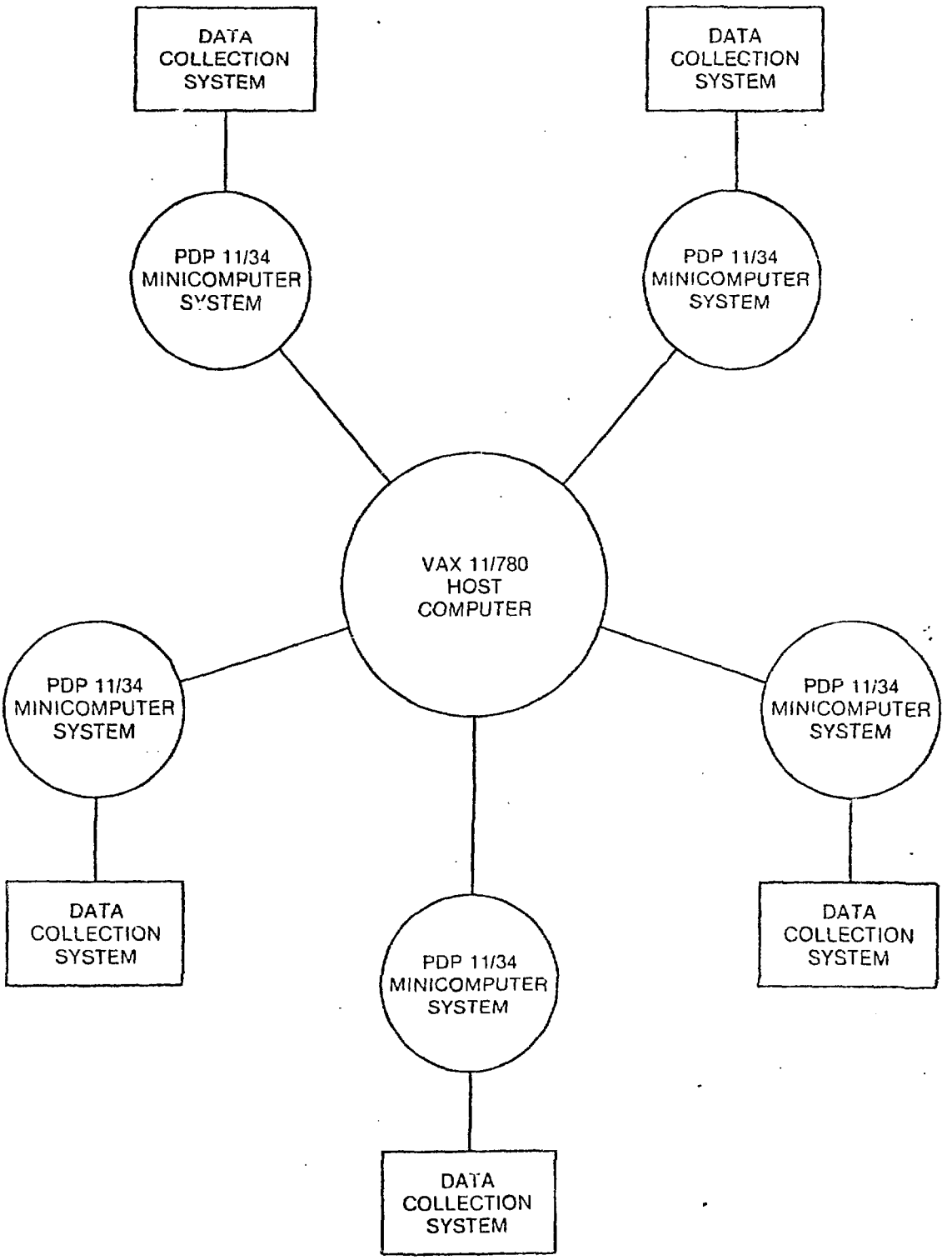

DATA COLLECTION SYSTEM
DATA COLLECTION SYSTEM
PDP 11/34 MINICOMPUTER SYSTEM
PDP 11/34 MINICOMPUTER SYSTEM
VAX 11/780 HOST COMPUTER
PDP 11/34 MINICOMPUTER SYSTEM
PDP 11/34 MINICOMPUTER SYSTEM
DATA COLLECTION SYSTEM
PDP 11/34 MINICOMPUTER SYSTEM
DATA COLLECTION SYSTEM
DATA COLLECTION SYSTEM

Figure 3

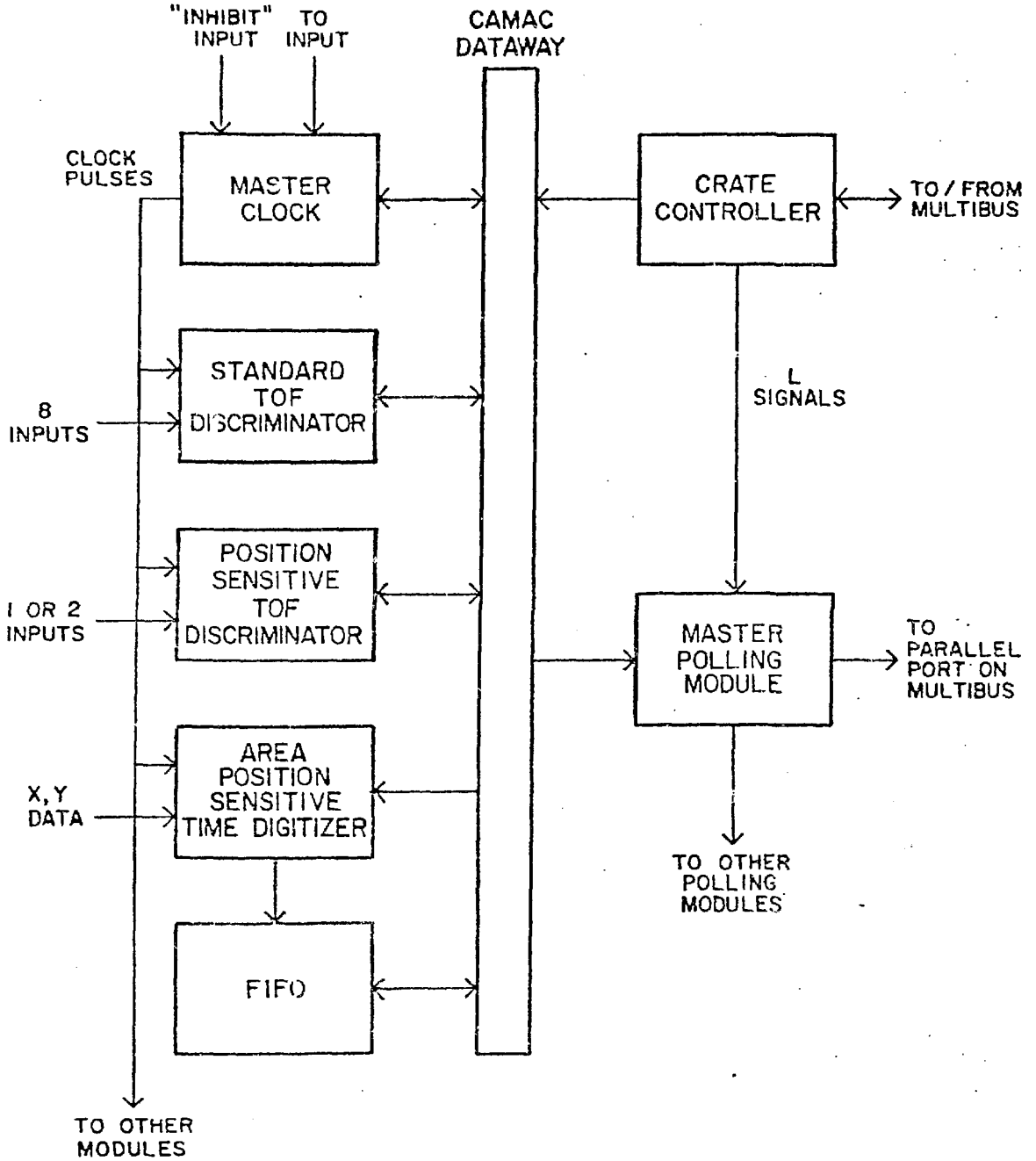

"INHIBIT" INPUT
TO INPUT
CAMAC DATAWAY
CLOCK PULSES
MASTER CLOCK
CRATE CONTROLLER
TO / FROM MULTIBUS
STANDARD TOF DISCRIMINATOR
8 INPUTS
L SIGNALS
POSITION SENSITIVE TOF DISCRIMINATOR
1 OR 2 INPUTS
MASTER POLLING MODULE
TO PARALLEL PORT ON MULTIBUS
AREA POSITION SENSITIVE TIME DIGITIZER
X, Y DATA
TO OTHER POLLING MODULES
FIFO
TO OTHER MODULES

Figure 4

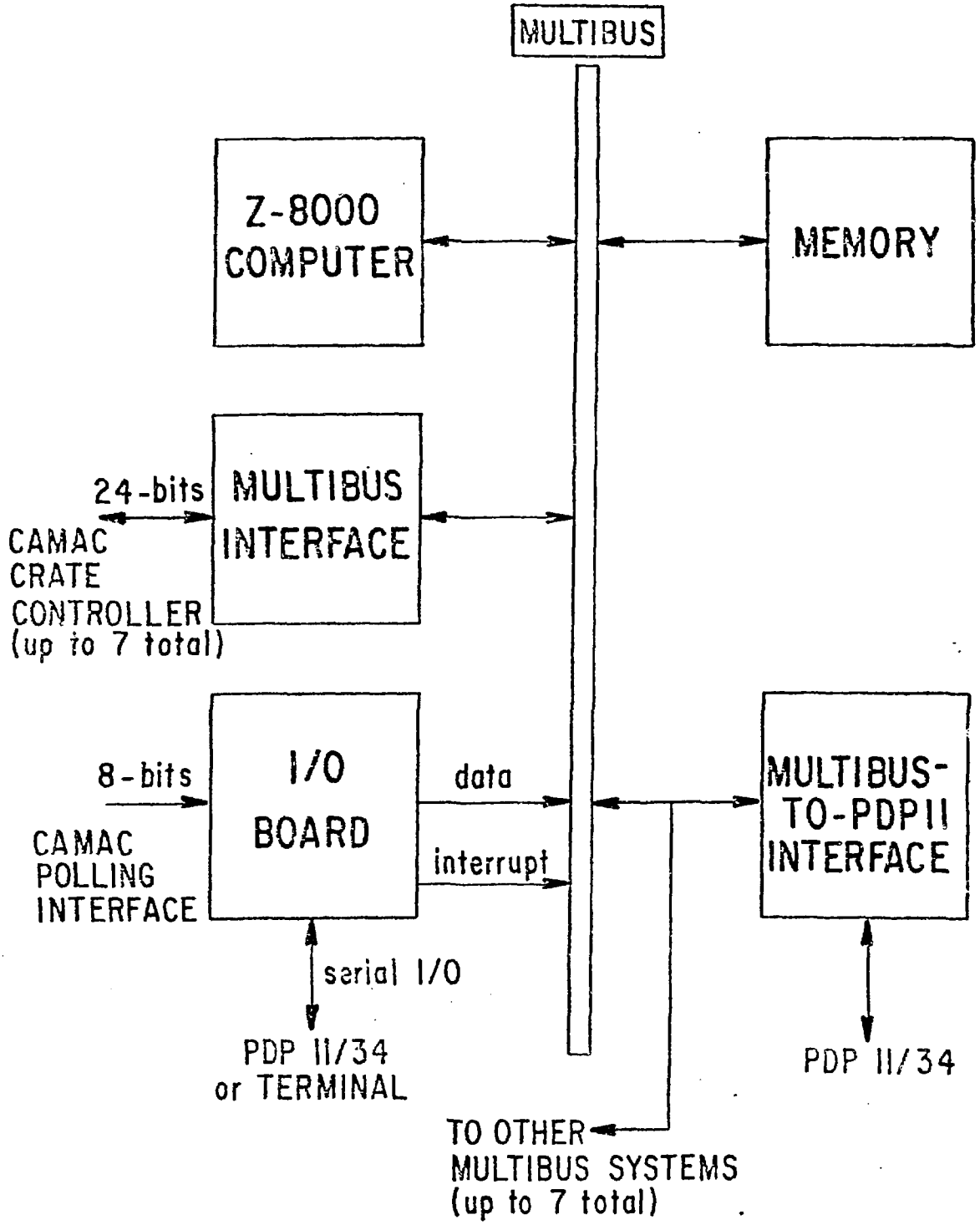

MULTIBUS
Z-8000 COMPUTER
MEMORY
24-bits
CAMAC CRATE CONTROLLER (up to 7 total)
MULTIBUS INTERFACE
8-bits
CAMAC POLLING INTERFACE
I/O BOARD
data
interrupt
MULTIBUS-TO-PDP11 INTERFACE
serial I/O
PDP 11/34 or TERMINAL
PDP 11/34
TO OTHER MULTIBUS SYSTEMS (up to 7 total)

Figure 5

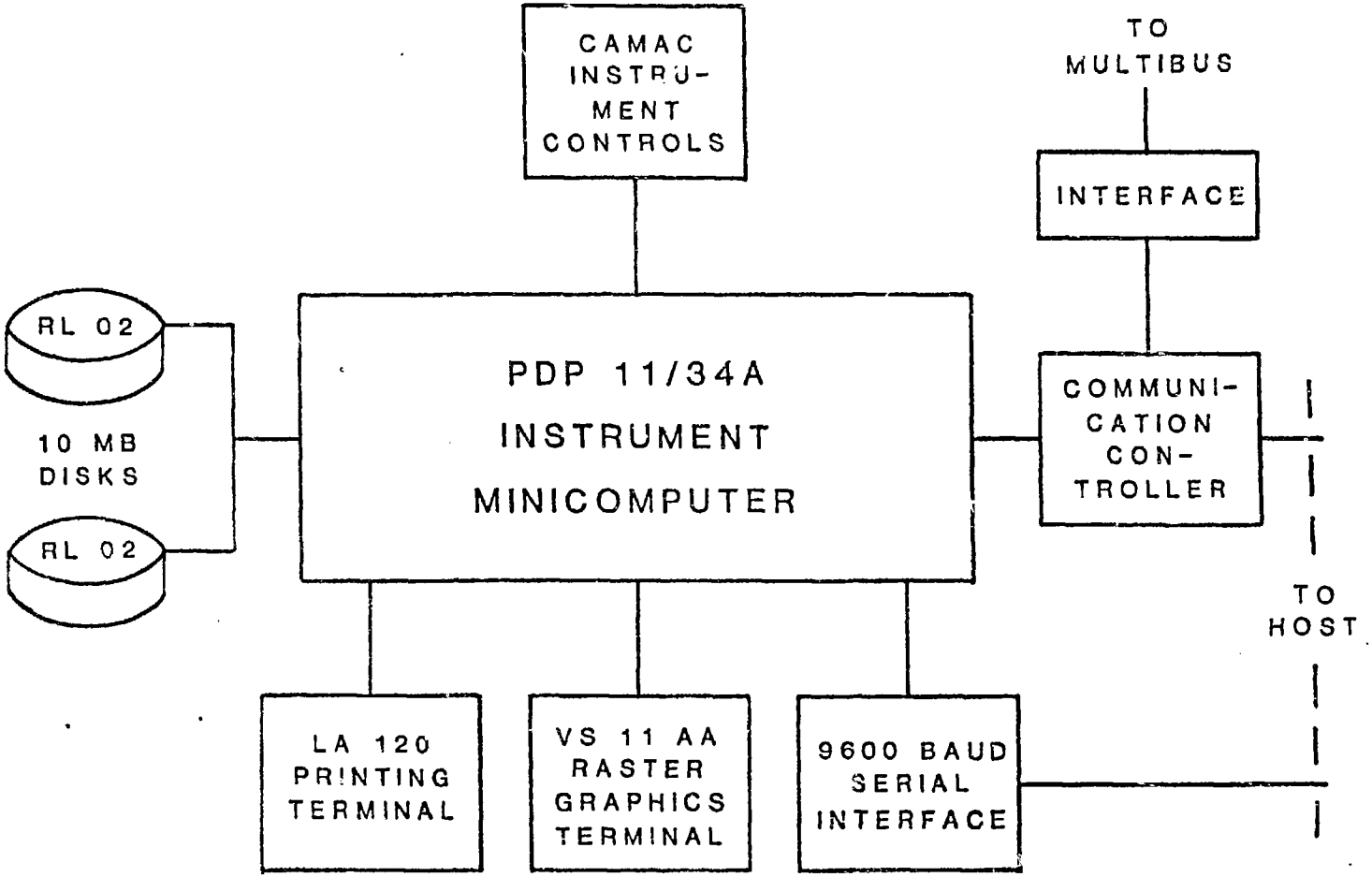

CAMAC INSTRU-MENT CONTROLS
TO MULTIBUS
INTERFACE
RL 02
10 MB DISKS
RL 02
PDP 11/34A INSTRUMENT MINICOMPUTER
COMMUNI-CATION CON-TROLLER
TO HOST
LA 120 PRINTING TERMINAL
VS 11 AA RASTER GRAPHICS TERMINAL
9600 BAUD SERIAL INTERFACE

Figure 6

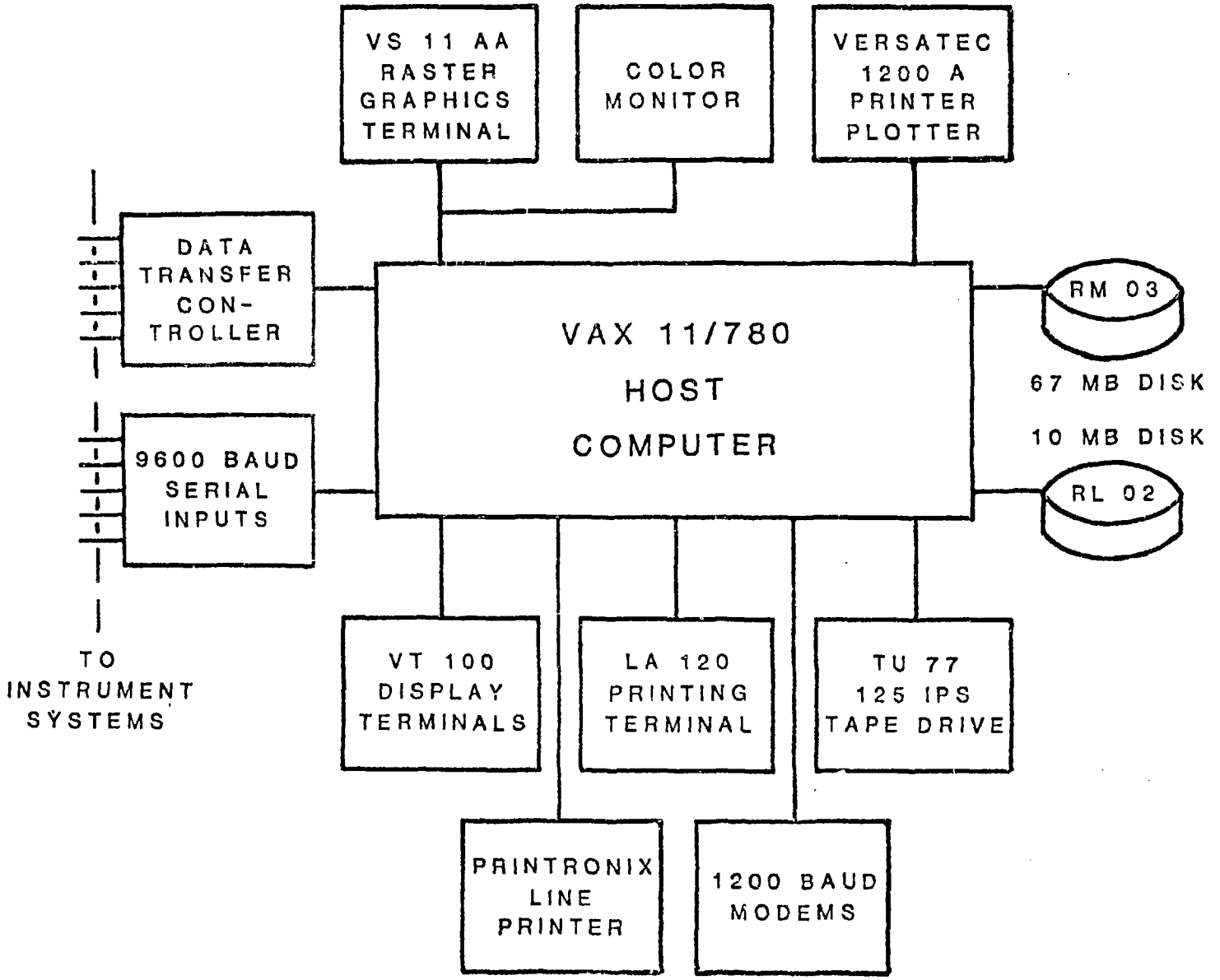
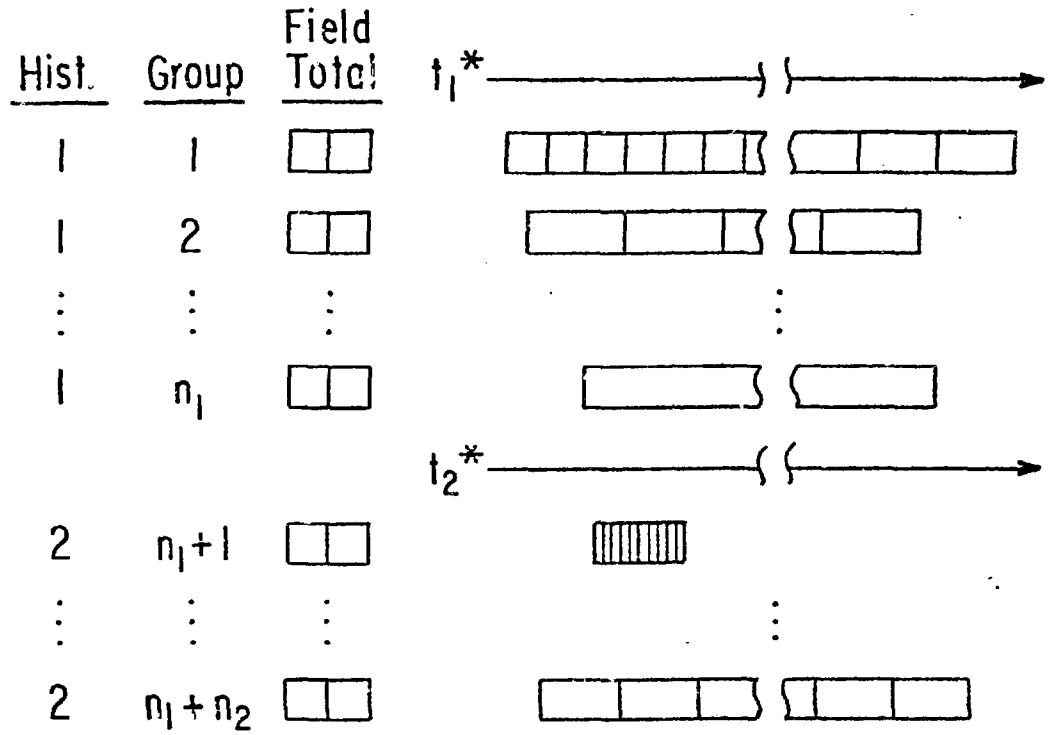

VS 11 AA RASTER GRAPHICS TERMINAL
COLOR MONITOR
VERSATEC 1200 A PRINTER PLOTTER
DATA TRANSFER CON-TROLLER
VAX 11/780 HOST COMPUTER
RM 03
67 MB DISK
10 MB DISK
RL 02
9600 BAUD SERIAL INPUTS
TO INSTRUMENT SYSTEMS
VT 100 DISPLAY TERMINALS
LA 120 PRINTING TERMINAL
TU 77 125 IPS TAPE DRIVE
PRINTRONIX LINE PRINTER
1200 BAUD MODEMS

Figure 7

Standard and Linear-Position-Sensitive Detectors



Area-Position-Sensitive Detectors

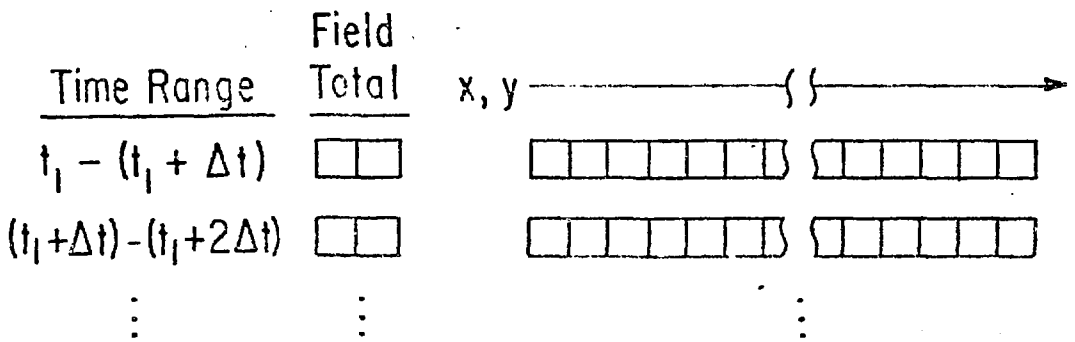


Figure 8

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