THE DZERO DOWNLOADING AND CONTROL SYSTEM

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The Fermilab DZero project is a large colliding beams detector for use at the Tevatron proton-antiproton facility. The size and complexity of this detector is such that the required controls and monitoring system resembles the control system of an accelerator. For this detector, the control and monitoring system is separate from the detector data gathering system. However, the monitoring system has access to all the registers in the digital section of the detector data system so that the control system may be used for testing and for downloading constants, such as pedestal and zero suppression data, to the detector data systems. This paper describes the design of the downloading, monitoring and controls system for the DZero detector, with special emphasis given to the reasons for design choices that were made.

Architecture

The overall architecture of the DZero downloading and control system is that of a distributed group of 68000-based local stations networked together using IEEE 802.5 Token Ring. All stations are housed in VMEbus crates. A MicroVAX is used as a gateway between Token Ring and Ethernet, the network used for the host VAX computers. Figure 1 is a schematic of the system architecture.

* Operated by Universities Research Association, Inc. under contract with the US Department of Energy.

There are three areas in the DZero facility; the detector itself and the platform that supports it, the movable counting house, and the fixed counting house. The platform houses most of the analog signal processing electronics. The movable counting house contains the digitizers, first level trigger electronics and the control system computers. Host computers and the MicroVAX farm that forms the second level trigger are located in the fixed counting house.

Design Choices

The DZero detector has nearly 100,000 channels of electronics and an average event size of 300 K bytes. The level 2 trigger system is designed to process 400 events per second so the average data rate from the detector is 120 M byte per second with peaks that are several times as large. In order to meet these specifications and yet keep the design fairly simple, we decided to divide the data path into 8 unidirectional segments. Although each of the 8 sections are assigned to a detector sub element, the elements were grouped so that the data rate per section is as similar as possible.

The unidirectional feature means that data only flows up the chain towards the level 2 trigger so no routing tables or other control functions are required; the data path is determined by the wiring. This simplifies

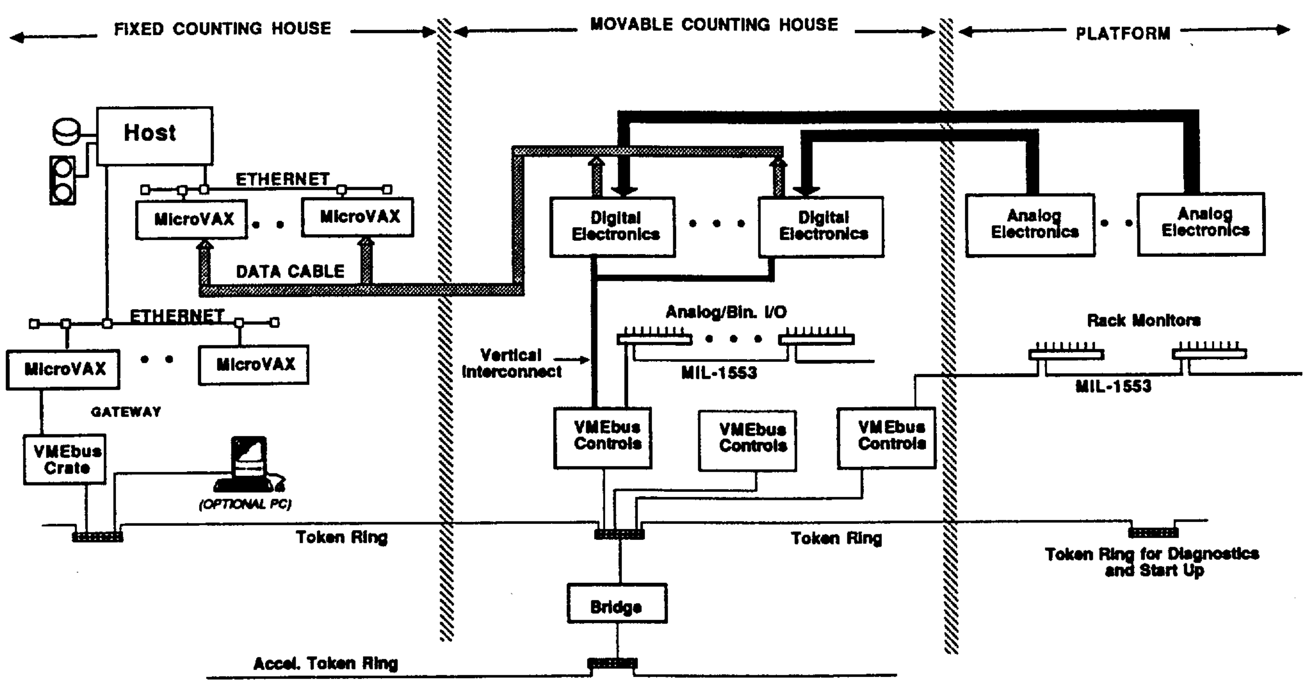

Figure 1. System Architecture for the DZero Detector

the overall system design. However, many of the digital devices in the acquisition chain have constants that must set so we had to provide a bidirectional path to access them. This second data path is through the control system.

The control system access to all the digital crates has several additional advantages. Since it is a simple serial system that can be readily broken into segments, one can use it to test (at low speed) parts of the detector as they are installed; the entire data acquisition system does not have to be operational. The high speed data path can be tested by loading data into the acquisition electronics from the serial path, transferring the data at full speed to the MicroVAXes and then comparing the results. The production board and subassembly testing system can run on the experiment with little or no modification. The latter requires that the test system be compatible with the network but since the serial network can work with one crate, this is not difficult. Personal computers and embedded controllers can easily be attached to the network so specialized functions such as pulser calibration can be done with local processors as well as the central computer system.

The digital control system runs asynchronously with the data acquisition system. There are also many microprocessors involved. Both of these features can cause noise in the low level analog electronics. Thus we decided to have no microprocessors on the DZero platform. This means no digital VMEbus crates on the platform. Instead, we developed a small remote readout module that is controlled from a VMEbus crate in the movable counting house via a MIL-1553B serial link. If noise is a problem, this link could be shut down during normal data taking and then activated for a short time every few seconds to read such things as voltages and temperatures. We could suspend data taking during this time. This suspension would contribute about 1% to the total dead time. Although the link is designed to be shut down, it would be simpler to run the system without doing so. Thus, we are attempting to design a very low noise monitoring module.

The physical packaging for both analog and digital DZero electronics was chosen to be Eurocard hardware. Crates needing digital services are required to have a VMEbus P1 backplane and a P2 backplane if 32 bit transfers are needed. Choice of these well-defined standards has allowed research groups at different institutions to design components for the data system that work together and with commercially available processor and I/O cards.

The economics of building high energy physics electronics favors card sizes larger than the 6U by 160 mm VMEbus format. As a result, most of the detector electronics are fabricated on 9U by 280 or 400 mm circuit boards that are fully compatible electrically with VMEbus P1 and P2. The fact that the oversized card format is not covered by the VMEbus specification has had little impact.

The control computers are also VMEbus (6U by 160 mm) systems that are interconnected with the local area network. These are small diskless systems that function as embedded processors. Their normal functions are to read analog and digital data, such as power supply voltages and currents and rack and cooling water temperatures, to scan the data for alarm conditions, and to make selected data available to any network requestor. With no active requests for data, only alarm messages are routinely sent to the higher level computers.

Any control station may connect to several crates of detector electronics via a memory mapped vertical interconnect which is a bus extender that transparently maps blocks of control station memory into slave crates. This arrangement allows the VAX computers, or any master on the network, to access any memory or control register in the entire DZero digital system. Several VAX programs or network masters can simultaneously access detector or monitor data, a capability that will be particularly useful during the installation and test phase of construction.

Because the local stations contain the data base for the equipment they control and because they support a local console, they can be used independently to develop and test subsystems with no VAX support. Systems developed elsewhere can be plugged into the local area network to make their data available to the entire system. Local stations are identical except for the database that describes the parameters for a given station. Each station will read between 500 and 1000 analog channels of data, and additional stations can be added as needed.

Hardware

All DZero digital electronics are structured around the VMEbus backplane. The control crates are VMEbus standard; however, to achieve the required channel density for the detector data digitizer crates, an oversized Eurocard format is used. These cards maintain the VMEbus P1 specification and use the normal row B of P2 to accommodate 32 bit transfers.

The detector data digitizer cards store data in on-board memory that is accessible from VMEbus. All constants such as zero suppression thresholds and command/status registers are also accessible as VMEbus data or I/O. Following an event, data in each crate is collected over VMEbus and buffered in the data cable driver card, for subsequent transfer to the MicroVAX second level trigger computers. There are eight data cables for the entire detector.

Detector data crates have no CPU installed but have two masters; the data cable drivers that collect event data from the digitizers and the vertical interconnect, an interface card that allows a control system crate to read and store data in any of several data crates. It is the vertical interconnect that is used to download constants to the detector data crates. The constants are sent via Ethernet from the host VAX to the MicroVAX gateway and then by Token Ring to the appropriate control system crate that deposits the constants into the selected memory or I/O registers. Note that the vertical interconnect adds no overhead to this operation; the slave crates are accessed as memory in the master crate.

Local Control Stations

The DZero control system is a distributed network of stand-alone microprocessor based systems. Each local station controls and acquires data from a portion of the detector. A local database is maintained for the equipment monitored and controlled by each station. This database is stored in nonvolatile RAM to allow the system to operate without downloading, following a power outage, although the database can be downloaded from or uploaded to the VAX host computers.

A local station periodically reads all its analog and digital data, scans the data for out-of-tolerance alarm conditions, provides data to any remote requestor, and supports an optional local operator's console. All control system data can be read and monitored at a repetition rate of 15 Hz.

Because alarm scanning is done locally, network traffic is minimized. Only requested data are returned to requestors rather than routinely sending all data to a central computer to be scanned for alarms.

Local Station Hardware: Four cards are required for a basic local station: a commercial 68020-based CPU card, a non-volatile memory card, a Token Ring adapter card and a crate utility card. In addition to the basic system, interface cards are needed for I/O.

In the DZero project nearly all control system data acquisition is done using MIL-1553B data bus. A VMEbus 1553 controller card was designed to operate two independent 1553 bus cables. This single card is used to access about a thousand analog channels of monitor data. Because each local station consists of only a few cards, two separate local control stations can occupy a single Eurocard crate, each using its own backplane.

The crate utility board contains mode switches, status lights, system timers, and support for a small local console. Using the local console, the operator can interact with the local system or any other system on the network.

The CPU card for the local systems will be a Motorola MVME133 68020-based card. Tests are currently being done using a Motorola MVME101 68000-based CPU card, but the upgrade to the 68020 processor allows a single local station to accommodate more channels of data thereby reducing the number of stations required.

Data Acquisition: As mentioned above processors are excluded from the DZero collision hall. Thus a data acquisition method was needed for the monitoring system that could acquire data without the use of processors on the platform. The MIL-1553 bus performs this function by interconnecting several non-intelligent monitor boxes and a local control station in the movable counting house. Monitor data includes parameters such as power supply voltages and currents, water and air temperature measurements, and digital status readings.

Because of the repetitive nature of the monitoring requirements, a monitor chassis was designed that accommodates the needs of a relay rack of DZero electronics. This chassis, called the "rack monitor" includes a 64 channel differential A-D, eight channels of 12 bit D-A output and 32 bits each of digital input and output. Physically, analog inputs are connected to the chassis with four 37 pin "D" connectors each containing 16 differential signals. Similarly, digital I/O is connected using a 37 pin connector to interface 16 bits of data with alternate conductors grounded. The eight D-A outputs are arranged with 4 signals on each of two 9 pin D connectors.

The rack monitor consists of a baseboard that contains the power supply, the 1553 interface, the digitizer and half of the I/O connectors. A daughter board attached to the baseboard doubles the I/O capability of the chassis. The rack monitor appears to satisfy the needs of most racks on the platform as well as those in the movable counting house. There are approximately 72 racks on the platform and 25 racks on each of three floors in the movable counting house.

Although preliminary tests indicate that the rack monitors produce a rather small amount of electrical noise, it is possible to synchronize the data collection of monitoring and event data through the trigger system. The MIL-1553 bus has no continuous clock, so it is quiet except during data transmission time. It is hoped that the monitoring data acquisition can be made quiet enough to allow monitoring to be done without interfering with normal detector data acquisition.

A typical rack may have three chassis of electronics. Each chassis connects directly to the rack monitor all power supply voltage and current measurements. Several rack monitors are daisy-chained together and the single twisted pair 1553 cable is routed off the platform to a 1553 controller module mounted in a VMEbus control crate in the movable counting house. A typical row of eight racks on the platform contains 512 analog channels. Two 1553 cables connected to a dual-channel VMEbus 1553 controller module will interface 1024 channels to a single local control station.

Muon System: The DZero muon system includes 176 drift chamber modules distributed in three layers around the outside of the detector. Each module needs D-A control of calibration pulses, and monitoring of analog parameters such as gas flow and power supply voltages. A monitor board tailored to the needs of an individual muon module was designed to mount with the signal processing electronics of each detector module. The monitor board is interfaced as a 1553 remote terminal and driven by a VMEbus controller in the movable counting house in the same way as the rack monitoring systems. Each muon monitor module contains 16 A-D channels, 4 D-A outputs and one word each of digital input and output.

Network Adapter: The Token Ring network adapter card is a straightforward VMEbus implementation of the Texas Instruments TMS-380 chip set. Although the card we are currently using was designed and built at Fermilab, commercial versions of TMS-380 based VMEbus cards are now becoming available.

Downloading Systems

In the DZero detector, there are several megabytes of constants that need to be loaded into the digital crates. It would be possible to put every digital crate on the serial network. This is expensive both in crate space and in money. Instead, we designed a very simple VMEbus vertical interconnect card which maps memory in a master crate to 5 slave crates.

A vertical interconnect master card in a control system crate drives a single 64 conductor cable that daisy chains to several slave crates. Slave crates are each allocated one or two megabytes of space in the master VMEbus address space. A four bit switch sets the address of each slave crate and determines what master addresses will appear in the slave crate. A second four bit switch sets the upper four bits of the local 24-bit address that will be asserted in the slave crate. This memory mapping is shown in Figure 2.

The vertical interconnect was specifically designed to allow a master crate to access multiple slave crates in a completely transparent way. Slave crates cannot initiate a transfer, there is no bus arbitration for use of the vertical interconnect cable and interrupts are not supported.

The single 64 conductor cable contains 24 bit address, 16 bit data, and the data transfer strobes. Trapezoidal drivers are used for address and data; the differential line drivers are used for the strobes. The control crate that contains the vertical interconnect master will be located close to the slaves, so the vertical interconnect cable will typically be only a few meters long.

In order to exercise the 32 bit transfer capability of the digital cards in the slave crates, buffers are provided on the vertical interconnect to allow successive 8 or 16 bit transfers to perform 32 bit transfers in the slave crate. This is done transparently by arranging for a slave crate to occupy two megabytes of the master's memory map where the first megabyte performs byte and word accesses in the slave and the second megabyte does only 32 bit read and write operations in the slave. This capability is only needed for testing, as the data cable drivers utilize 32-bit access to the slave crates.

In addition to the one or two megabytes of memory space, each slave crate is allocated a full 64K bytes of short I/O space. The I/O space for all slave crates resides in a one megabyte block of the master's memory. The vertical interconnect board also contains a 4-level priority bus arbiter and the other normal VMEbus slot one functions.

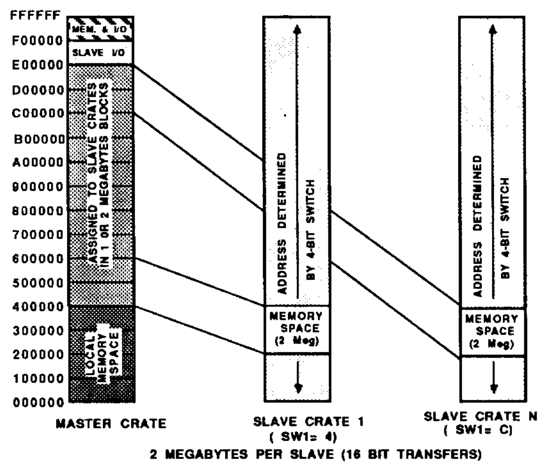

Figure 2. Memory Map of Vertical Interconnect

High Voltage System

A new VMEbus based high voltage system is being designed for DZero. Tentatively eight high voltage modules will be plugged into a 6U by 160 mm VMEbus baseboard. The baseboard contains a multiplexed 16 bit A-D, eight 16-bit D-As for high voltage setting, eight 12-bit D-As for overcurrent trip setting and a front panel voltage maximum setting potentiometer. An overcurrent/overvoltage trip circuit will shut down a supply and assert a digital trip output signal that can be combined with other trip signals to cause a group of supplies to trip due to a fault in any member of the group. Supplies are grouped by installing jumpers on a special P2 backplane. This backplane also includes geographic addressing connections so that onboard address switches are not needed. There is an option to put switches on the baseboard so that the unit will run with only the P1 backplane.

The rather simple high voltage supplies are read and controlled by a dedicated 68000 based CPU that will provide software ramping and maintain a database of present high voltage values and supply currents. High voltage readings will be recorded in RAM so that the operation of all supplies for the recent past can be made available to any remote requestor. Using data stored in memory, a local personal computer can generate displays of high voltage supply operation. The present design is for modules that are the width of three VMEbus slots (12 h.p.). Six of these modules, or 48 channels of high voltage, will fit in a 6U crate along with the 68000 CPU, a memory card and a vertical interconnect. The DZero detector needs about 600 independent channels of H.V.

Groups of high voltage crates will be connected to the control system crates using the vertical interconnect. Individual high voltage channels and their current readings can then be treated like any other control system parameter. Analog and digital alarm scanning and reporting will be handled in the usual way.

Software

The software used in the VME local stations has evolved from that designed for the Fermilab Linac control system installed in 1982. Enhancements are being added to accommodate an order of magnitude larger number of data channels per station and to generally increase the functionality of the data request and setting commands interface.

Local Control Programs

The local station system software consists of tasks and interrupt service routines. Interrupts processed by the system support the Token Ring network, 15Hz synchronization, RS-232 serial ports, and the 1553 controller. The tasks provide for support of network command processing, data acquisition, fulfillment of data requests, alarm monitoring, serial communications and a local console.

Data Acquisition: Nearly all the control system data will be accessed via the 1553 interface. Each 1553 dual controller VME card can acquire data from 60 remote terminals (RTs). Each rack monitor is interfaced as one of these RTs. One VME station is expected to deal with approximately half this many, so that one dual controller will suffice per VME station. We expect to operate both controllers simultaneously for routine data collection. We know that 68000–based VME stations digitize and collect 32 channels of A/D data in 1 ms using a single controller. We expect that using the dual controller in a 68020-based VME station will allow access to 30 sets of 32 channel A/Ds in about 15 ms, which is expected to be its typical load.

Monitoring: Each analog channel and each digital status bit may selectively be included in the alarm monitoring task's scan for a change-of-state, which may be an analog channel reading going outside (or inside) its tolerance window or a digital status bit toggle. Such a change-of-state results in an alarm message being posted to the network node designated to receive and process alarms.

Network Interface: The Token Ring network software merely lets the TI chip set do most of the work. When an error-free frame addressed to the VME station has been DMA'd into VMEbus memory, the system is interrupted. During interrupt processing, any additional frames addressed to the station are accumulated into the fast memory local to the chip set, awaiting the chance to be DMA'd into memory, as the software gives the nod. Thus, the real-time requirements on network communications software are drastically reduced from what they were in the old days (1982). It means, for example, that serial port character interrupts at 9600 baud may be assigned a higher priority than the network interrupts.

Network Communications: The network software supports a flexible interface to any data in the control system. Requests for data may identify channels whose data reside in any set of network nodes. The response fragments are collected and re-arranged for the requestor. This service is designed to reduce network overhead for the requesting node.

Serial Communications: The Serial Server software supports an RS-232 connection into a local station. This allows any computer with a serial port to access and control data of that local station and of other stations on the network with the full functionality given to any network node. The only limitation is that of the baud rate used. The inherently binary data is encoded into a hexadecimal ascii format similar to Motorola S-records.

Local Console: A video RAM alphanumeric display and a special serial interface to a console assembly consisting of a CRT, keyboard, knob, buttons and lights is supported by a set of application programs which reside in the memory of each local station. It is used to check out hardware, edit the local database, debug software, and provide generalized access to data of local or other network nodes.

Downloading

The physics data crates are accessible via the vertical interconnect, as described above. Hence, constants to be downloaded are merely settings of data values to be copied by the VME system across this logical extension of the VMEbus. Requests for data can similarly be fulfilled by simply copying the memory mapped data.

High Voltage

The high voltage controller software will operate as an auxiliary processor in a slave crate accessible over the vertical interconnect by a (locally) standard VME station. Its controller functions will require that it shepherd the ramping of groups of power supplies in a controlled manner. It may even have to watch that each power supply respond as expected to the steadily increasing series of high voltage settings. The software will not, however, have the responsibility of forcing trips of other supplies in a logical group of supplies when a given supply trips, as that is handled by hardware as described above.

An additional feature will be provided for a local PC connection to the VME system crate. This will allow the use of display software already developed at Fermilab to monitor these high voltage power supplies, during the time that the DZero online monitoring system is being developed. Besides, a PC is still cheaper than a MicroVAX.

Present Status

All elements of the system described here have been built and tested with the exception of the high voltage system. Download data from a VAX has been sent through the Ethernet-Token Ring gateway to a control crate and stored in a slave digitizer crate. Constants have been read back using the same path. For the ongoing DZero beam tests, monitor data is being collected using MIL-1553 rack monitor chassis.

Several aspects of the system are still being developed:

1) A Q-Bus to VMEbus interconnect is being used so the MicroVAX gateway can use the existing VMEbus Token Ring card. A Q-Bus Token Ring card is being developed, and a commercial adapter may become available soon.

2) Early tests of the system use a 68000 processor board. The software will be ported to the 68020 board.

3) Software for the local stations is being modified to increase the number of data channels that can be accommodated, and to update the network message protocols.

4) The high voltage system is still in the design stage, although tests of a prototype of the high voltage module indicated that the channel density of 48 channels per crate (8 - supplies/module) can be achieved. VMEbus high voltage modules should be available by the end of this year.

The D0 detector is scheduled to be operational in 1989, but a partial test in the beam enclosure is planned for sometime in 1988. As soon as the counting house and the platform relay racks and associated utilities are in place, the control system crates and rack monitors should be installed so that the monitoring system will be available to support the check out of the detector electronics.

Acknowledgements

The system described here is the result of the combined efforts of many people. Tom Droege is responsible for the high voltage modules used in that system. Al Frank and Rich Mahler are responsible for the rack monitor and the muon monitor modules. The Q-Bus to Token Ring interface is being designed by Elton Anderson. Many colleagues and DZero collaborators have contributed to the design and implementation of various parts of the monitor system.