CONF-8405162--3

CONF-8405162--3

COO-3130TC-19

DE84 014112

THE D0 EXPERIMENT : ITS TRIGGER, DATA ACQUISITION, AND COMPUTERS †

Authors:

D. Cutts, R. Zeller, Brown University; D. Schamberger, S.U.N.Y. - Stony Brook; R. Van Berg, University of Pennsylvania (presented by D. Cutts) *

Abstract:

The new collider facility to be built at Fermilab's Tevatron-I D0 region is described. The data acquisition requirements are discussed, as well as the hardware and software triggers designed to meet these needs. An array of MicroVAX computers running VAXELN will filter in parallel (a complete event in each microcomputer) and transmit accepted events via Ethernet to a host. This system, together with its subsequent offline needs, is briefly presented.

THE D0 EXPERIMENT

The D0 project is an experiment to study pp interactions at the D0 intersection region at Fermilab's Tevatron-I colliding beam accelerator. The collaboration at present consists of 12 institutions[1] with Paul Grannis of Stony Brook as spokesman. It is fair to say that this experiment is the "most approved" of any current project. Because of funding uncertainties we have over the past year been repeatedly reviewed, always with positive results; and I'm happy to say that finally appropriate commitments are forthcoming.

At the Tev-I, the expected signatures of new physics at 2 TeV involve high p_t leptons and jets (as from massive intermediate states) or large missing p_t (carried off by neutrinos, say). As will be seen, these event characteristics will be used by the hardware trigger; but more fundamentally they provide the basic goals for our detector design; to optimize the lepton (electron and muon) and photon identification and energy measurements at the same time as maintaining the best possible energy and angular resolution for jets.

To be both competitive with and complementary to the other detector at Tev-I (CDF, at intersection region B0) we have concentrated on a design with superior lepton measurements and calorimetry, while doing without a central magnetic field. The detector will have three basic divisions, beginning with a central tracking section surrounding the interaction point and extending radially to 70 cm. This device will include a transition radiation detector providing an independent hadron/electron rejection of order 50/1. Surrounding the central tracking will be a uranium (and copper)/liquid argon calorimeter extending over the full angular range, to within 1 degree of the beam. This calorimeter will be divided in two sections: an electromagnetic region with fine sampling and a hadronic part with coarser sampling. Outside the calorimeter will be a muon detector, consisting of planes of proportional drift tubes spaced about three magnetic iron torroids. A full description of the detector is available[2].

To give a measure of the real strengths of the detector, some parameters for the central calorimeter and the muon detector are shown in Table 1. Note the superb calorimeter energy resolution, the fine segmentation in towers, with multiple samplings, and the near equality of electromagnetic and hadronic response, a feature of this type of calorimeter. The muon detector extends over nearly the complete angular range; with the large total absorption length, hadronic punch-through is minimized.

*Invited talk given at the Symposium on Recent Developments in Computing, Processor, and Software Research for High-Energy Physics, Guanajuato, Mexico, May 1984.

DATA ACQUISITION OVERVIEW

The D0 detector, with approximately 100,000 separate channels of electronics, will reside in a region where the interaction rate is of order 50 KHz. In the detector, the typical size of an interaction event will be rougly 60 K bytes, including both digitized data and address. We will handle this data flow with two sequential trigger systems, the first done quickly with hardware and the second more slowly with software. Given an interaction, fast output signals from summed elements of the detector will flow into custom designed hardware capable of filtering events with a rejection factor of roughly 250 within the time between beam crossings (3.5μsec). Although complicated, such an electronic trigger is standard and straight forward to build (see Figure 1).

In order to reduce the number of events saved on tape or disk to one or two per second, a further selection will be necessary, with a rejection factor of order 100/1. Implementation of this step will also be straight-forward, since it will be based on commercially available (and supported) hardware and software. At this stage, event selection will be made with a filter program, with of order 100K - 200K instructions on average needed per event. Several microcomputers, capable of handling the filter requirements, are commercially available now or in the near future. These include projected MicroVAX units as well as those based on the Intel 286/386 series and on the Motorola 68000 series. Analysis in these microcomputers will be done in parallel, each essentially an isolated system receiving an event directly and analyzing in completely. We have chosen as this microcomputer the MicroVAX[3] ;for the Level-2 trigger we will have an array of MicroVAXes each running VAXELN and each linked via Ethernet to a central host VAX, which will collect those events surviving all filtering.

The structure of the data acquisition system is shown in Figure 2. The fast electronics digitization and readout crates will be grouped into 7 sections; each section reading out on its own data cable, which will be daisy chained to each microcomputer in the array. A separate MicroVAX, the "Acquisition Supervisor", will control the event flow - allocating the data cable within the readout section and assigning which analysis MicroVAX will receive the event. For its control functions, the Supervisor will be interfaced to all elements of the acquisition system: the Level-1 trigger, the readout crates, and the Level-2 analysis units.

LEVEL-1 TRIGGER

The hardware trigger decision will be made in the 3.5 microsecond interval between beam crossings. The fast response together with the double-buffering of the input analog signals will insure that deadtime associated with this trigger will be minimal. As input to the Level-1 trigger, signals from the calorimeter towers will be grouped in towers 4x4 laterally and summed in depth; thus there will be available a fast calorimeter signal from each dimension of 22.5 degrees in azimuth and 0.4 units of rapidity, for a total of 16x25 = 400 e.m. and 400 hadronic trigger towers. Also present will be data from the TRD, from the muon detector, from the interaction tagging scintillation counters (the "Level-0" trigger) and from accelerator monitors, as well as a 3-bit vertex position measurement from the central detector. This last data may not be available within the initial decision time, but may be used as a "Level-1.5" since a corrected angle can make a significant improvement in transverse energy calculations.

Figure 1 shows the design of the Level-1 trigger[4]. In addition to the detector data, various signals which will be preset externally control the response of the trigger hardware to each event. Listed in Table 2, these signals define such parameters as thresholds for transverse energy or transverse momentum in the electromagnetic and hadronic calorimeters, and minimum energies for the "jet finder". These signals also will allow the definition of particular trigger types as some combinations of the separately-tested event characteristics.

LEVEL-2 TRIGGER

The Level-2 trigger will be accomplished by routing the complete data for one event from the digitization crates to one microcomputer which runs the entire filter program. In this mode the micros will operate in an independent but parallel fashion. As discussed previously, of several commercially available microcomputer systems, we have chosen for these units the QBUS based MicroVAX family. We expect that its performance will be comparable to that of a VAX-11/780, that it will have sufficient direct memory for the complete analysis program and event data, and that it will be available on a time scale suitable to our experiment. To provide a means of loading the data into the analysis unit, one of us (R.Z.) has designed a dual-port memory board using 64K static rams. The external port cycles at 100 nsec. with a 32-bit wide input, for a bandwidth of 40 Mbytes/sec. We plan to have eight dual-port input channels per Level-2 box loaded in parallel with event data and accessed by the MicroVAX via QBUS block mode transfers.

The MicroVAX units will be interfaced to the digitization crates via data cables which carry a few control lines supporting a simple protocol (no handshaking) as well as the 32-bit wide data lines. Each of the units will be linked to a host VAX via Ethernet for shipment of events which pass the software filter as well as for initial program downloading. To enable real-time control of the acquisition process, each unit will also be linked (to the Supervisor) via "extended registers". We expect to incorporate in the system approximately 50 MicroVAX processors to meet the Level-2 trigger requirements.

As indicated above, the Supervisor will be a separate MicroVAX (running a separate VAXELN task) which will exercise the data acquisition control functions, such as deciding:

1. which Level-2 unit is free and should receive the next event;
2. which Level-1 triggers should be enabled;
3. given a Level-1 trigger, which electronics readout crates should initiate digitization;
4. as digitizations complete, which crate should use the data cable associated with its readout section.

In addition to the seven data cables associated with the readout crates, one cable will be used by the Level-1 trigger to ship the fast trigger data (about 4 Kbytes) directly to the Level-2 analysis unit. Preliminary analysis of this data can give rise to a fast abort signal communicated to the Supervisor, which in turn could terminate unfinished readouts and reset the digitization buffers.

Another way in which the Supervisor will exercise a central control over the data taking is its loading an external "fast trigger memory". This simple interface acts as a matrix, with one dimension being lines associated with each of the different hardware triggers and the other dimension providing the corresponding patterns of electronics crates which should initiate digitization. For calibration and test data, for example, the Supervisor will be able to allocate a specific, single crate to digitize and, if useful, to route the data to a specific analysis unit. Indeed, for testing, the Supervisor will also be able to direct a given event to be read into a number of Level-2 systems and analyzed identically. Because of its central role in the acquisition, the Supervisor will be connected to the host VAX via a separate Ethernet line.

A number of additional interfaces will be developed for the acquisition system. The various detector readout devices will transmit data via data cables described earlier. The simple protocol of these cables will allow straightforward interfacing of the special calorimeter electronics[5], CAMAC, and FASTBUS. To enable control of the digitization and readout process, and to permit downloading to local crate intelligence, interfaces similiar to the "extended register" used in the analysis units will couple each of the electronics crates to the Supervisor.

A key element in our design is the use of commercially available system software. With our choice of the microcomputer system, the new DEC software package VAXELN will provide the complete framework for development and operation of the Level-2 analysis software, encompassing the host VAX and all the satellite MicroVAXes. This "software product for the development of dedicated real-time systems for VAX processors"[6] runs as a task under VMS on the host VAX. The task image is then downloaded to the appropriate MicroVAX using Ethernet. The analysis software can be written entirely in high level languages: "EPASCAL" for the control functions and FORTRAN for the Level-2 filter code. Downloading from the host to the MicroVAXes is supported as is remote symbollic debugging. The VAXELN program in each of the MicroVAXes has little system overhead, yet is multitasking (each interrupt service routine can be a separate task), and has transparent Ethernet support. Thus a user at a terminal on the host can access any MicroVAX, and the VAXELN program in a MicroVAX can read and write the host's disks and tapes. This latter feature might make MicroVAXes an ideal choice for an offline analysis farm: events can be read from the host's data tape by VAXELN analysis packages running in each MicroVAX. All these aspects of VAXELN make it very desirable, especially since it is a currently available and supported product.

ONLINE AND OFFLINE COMPUTING

We plan to incorporate a large VAX (hopefully the "VENUS" will be available) as the central online computer for the experiment. This machine will serve as a host, for program downloading and reception of events passing the Level-2 filter. The host will maintain direct overall control over the data taking (via the separate Ethernet link to the Supervisor). This VAX will carry a large assortment of necessary peripherals and support the usual online functions such as displaying data.

In an experiment of our size it is important to consider the implications of saving events. Even with an event filter having an overall rejection factor of 25000/1 we will still collect events at a rate of 2 Hz. During the roughly 3 months per year that D0 operates, we will then require of order 8 Cyber 175-equivalents per year for the complete analysis. This result is based on an estimate[7] of 16 sec. of Cyber 175 time per event; adding in other offline tasks (Monte Carlo, reanalysis, development, etc.) yields roughly 16 Cyber 175-equivalents per year needed by our experiment. Still, this translates to roughly 100 MicroVAX-years, which may in fact be obtainable by microcomputer farms similiar to that described here.

TABLE 1. Some parameters of the D0 detector

Central calorimeter	Muon detector
depth: 7 λ	coverage 8° -172°
energy res.: $.37/\sqrt{E}+.005$ (had)	$dP/P \simeq 17\%$
$.11/\sqrt{E}+.005$ (em)	thickness: 13λ (90°)
seg.: 576 towers/4 sampl. (had)	18λ (10°)
3360 towers/4 sampl. (em)	punchthrough (min. E_π)
em/had. response ratio: 1.1	600 GeV (90°)
	5000 GeV (10°)

TABLE 2. Control Signals for the Level-1 Trigger

E_t electromagnetic thresholds	e.m. jet low energy cutoff
E_t hadronic thresholds	had. jet low energy cutoff
P_t electromagnetic thresholds	jet counter energy limits
P_t hadronic thresholds	AND-OR network programming

specific trigger prescaler ratios

specific trigger enable register

SUMMARY

The D0 experiment is facing data acquisition requirements that are extreme, forcing the use of parallel processors as the only commercially available means to obtain the necessary reduction in trigger rate. There is an extremely attractive option for parallel processing which will exist soon, an option with both hardware and software fully supported: the MicroVAX and VAXELN. We anticipate having a prototype acquisition system based on these products operational this year.

REFERENCES

1) Univ. Arizona, Brookhaven Nat'l Lab, Brown Univ., Columbia Univ., Fermi Nat'l Lab, Florida State Univ., Univ. Maryland, Michigan State Univ., Northwestern Univ., Univ. Pennsylvania, S.U.N.Y.-Stony Brook, Virginia Polytech. Inst.

2) "DESIGN REPORT, An Experiment at D0 to Study Antiproton-Proton Collisions at 2 TeV." The D0 Collaboration, December 1983 and later updates.

3) Units will be the "next in the family" after the currently available MicroVAX-I.

4) Questions about the design of the D0 hardware trigger should be referred to Maris Abolins or Dan Edmunds at Michigan State University.

5) Designed by the Columbia-Stony Brook (CUSB) group.

6) Digital Equipment Corp.: "VAXELN PROGRAMMING" page 1.1 (AA-Z451A-TE)

7) Bruce Gibbard, Brookhaven Lab. Questions about the analysis package or the central VAX should be referred to Bruce, while inquiries about the offline package should be made to Serban Protopopesou, also at Brookhaven.

† This work is supported in part by the U. S. Department of Energy and the U. S. National Science Foundation.

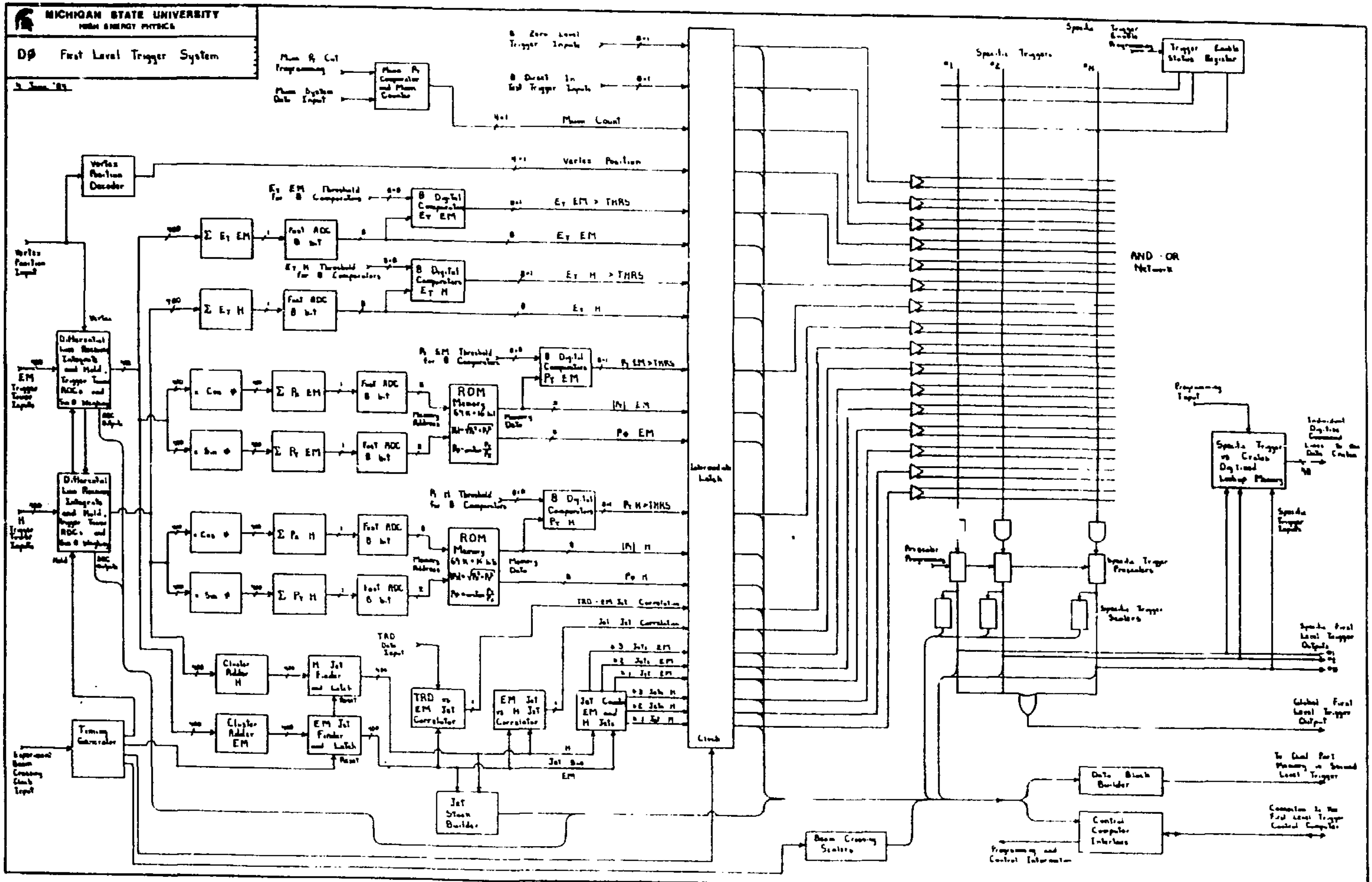
MICHIGAN STATE UNIVERSITY
HIGH ENERGY PHYSICS
DØ First Level Trigger System
Muon Count
Vertex Position
Vertex Position Decoder
Σ Eт EM
Σ Eт H
Eт EM > THRS
Eт EM
Eт H > THRS
Eт H
ROM Memory
Intermediate Latch
AND - OR Network
Specific Triggers
Jet Jet Correlation
TRD - EM Jet Correlation
Cluster Adder H
Cluster Adder EM
Timing Generator
Jet Steam Builder
Beam Crossing Scalers
Data Block Builder
Control Computer Interface
Global First Level Trigger Output
Specific Trigger Prescalers
Specific Trigger Scalers
Trigger Status
Enable Register

Figure 1.

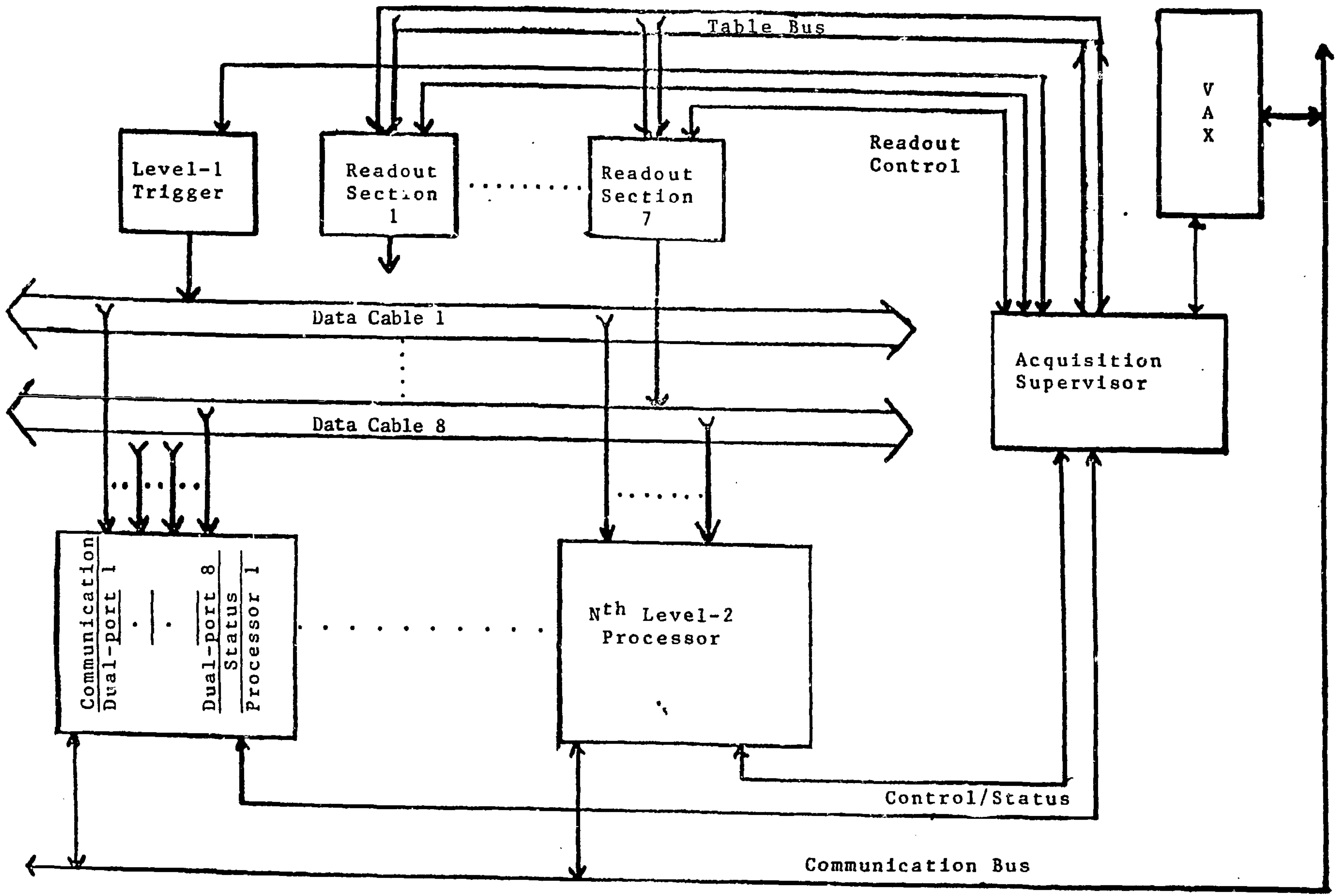
Table Bus
Level-1 Trigger
Readout Section 1
Readout Section 7
Readout Control
V A X
Data Cable 1
Data Cable 8
Acquisition Supervisor
Communication
Dual-port 1
Dual-port 8
Status
Processor 1
Nth Level-2 Processor
Control/Status
Communication Bus

Figure 2