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ABSTRACT

CAMAC is a digital data-handling system, incorporating a modular equipment approach, designed to communicate via a data transfer highway with a computer. Mechanical, electrical and logic features are specified to provide system compatibility. Developed by the ESONE Committee of European Laboratories, CAMAC has become adopted internationally as a standard for data acquisition and control.

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INTRODUCTION

The general instrumentation problem facing experimental scientists is the transmission of information concerning the location, time or energy ~~of a~~ specific event or observation or a series of such events or observations. These occurrences are detected by one or more sensors whose signal responses after some processing are usually analyzed by a digital computer. To minimize outside interferences it is appropriate to digitize the information as early in the information channel as possible. In like manner the general control problem is that of a digital computer issuing commands to one or more controllers in response to a pre-arranged instruction set and the observed data. In each case the information flow is ordinarily digital in nature, hence our interest in digital data handling.

In this light we are faced with a number of perplexing problems: 1) the construction of data-gathering facilities that will not suffer from early obsolescence, 2) the implementation of existing hardware that can readily be reconfigured or expanded, 3) the utilization of flexible software routines so that each new observation or experiment does not require the writing of a completely new program, and finally, 4) the meaningful interpretation of the resultant calculations.

CAMAC, a digital data-handling system, can be expected to offer real advantages in the first two considerations; work is under way on software problems, thus allowing scientists additional time and energy to undertake the fourth consideration, namely, the interpretation of the results.

For a brief historical view I must draw on experience in nuclear instrumentation. In early systems at nuclear research laboratories in the 1940's and 50's data were almost entirely reduced from photographs of cathode-ray tube displays or readouts of scaler counts or pulse-height analyzer channels. As equipment became more reliable, the complexity of the apparatus increased and the number of information channels multiplied. Soon we saw experiments employing up to several hundred channels of signal processors and storage registers.

Figure 1 gives some idea of the difficulty of keeping track of a complex data-acquisition system. Clearly means were needed whereby information from a number of parallel data sources could be sequentially connected to a common dataway feeding a computer. Thus, a multitude of different data-acquisition systems sprang up. At one point we had seven groups at our Berkeley Laboratory, each designing around a different data-handling system. A look across the country showed the problem to be universal. Again, it was clear that some consolidation was badly needed. Fred Kirsten, of our Laboratory, has pointed out that "data busing systems used by various laboratories and commercial firms in the United States share the common feature of being mutually incompatible..no one of the existing systems except CAMAC has had the necessary wide-spread acceptance and momentum to make it a practical condidate for alleviating the compatibility problem." [1]

Next, one may ask, "How does CAMAC achieve compatibility?" The answer is given with a certain amount of trepidation. We realize that the word "standardization" is an anathema to any self-respecting experimentalist. However, to achieve any compatibility some specifications need to be set down. Standards have been set for certain mechanical, electrical and logic aspects of data handling; in many other respects the implementation of a CAMAC system is left to the ingenuity and imagination of the designer.

To continue the questions, why should anyone in an observatory wish to standardize his stand-alone system? Also, if it is conceded that some standards are appropriate, how may a scientist faced with the selection of any of several small computers assure himself that overall performance is not that of the least powerful of all the computers available?

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[1] IEEE Trans. Nucl. Sci. NS-17(1), Part 1, 452 (1970)

ADVANTAGES OF INTERFACE STANDARD

Now that we have addressed the problems of data-handling standardization, what are some of the gains to be realized? For this one should review some of the very real advantages that have accrued in the Nuclear Instrumentation Module (NIM) program.[2] The NIM Committee was organized early in 1964; specifications were introduced that summer and first commercial components were displayed at the American Physical Society Meeting in January 1965. Since that time the NIM system has become accepted on this continent as the standard for nuclear instrumentation. Also European laboratories rapidly accepted NIM instruments in preference to a number of existing European standards. The NIM program, however, with few exceptions has been largely restricted to nuclear instruments; we are aware of little standardization in other areas of data acquisition and process control.

Some advantages of instrumentation standards are the following: Hardware of known capability is available and at an economical cost. Most scientists would be embarrassed to admit to the amount of time they and their students have spent haywiring together one-of-a-kind breadboards. The NIM concept largely eliminated the necessity and desire for each experimenter to come up with his own methods of construction. A data-handling standard could perform a similar function for computer interfaces.

A second advantage is the specification of logic levels, signal impedances, and supply voltages; these have become accepted throughout the world. In data acquisition the specification of integrated-circuit logic, e.g., TTL, and a data transfer sequence would be a first step toward compatibility among units designed by different laboratories and manufacturers.

A third advantage is that individual units such as analog-to-

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[2] Standard Nuclear Instrument Modules, TID-20893 (Rev 3), Louis Costrell, National Bureau of Standards, Washington, D.C. 20234

digital converters or scaling circuits can be completely designed, constructed, and tested without knowledge of the remainder of the particular operating system except that it be NIM-compatible. In a similar fashion standard digital components could be integrated into larger systems that have not yet been contemplated.

Another point, visiting physicists to laboratories such as CERN, Brookhaven and Berkeley make considerable use of the interchangeability of standard modules. Some equipment is borrowed; the remainder is furnished by the experimenter, but it is significant that the equipment is mutually compatible. I expect similar arrangements are made among astronomers.

Any standard is admittedly arbitrary; however, one should consider: What are the requirements for a viable data-handling system? A standard needs a read-write dataway capable of handling two or three bytes at a time, a command structure with the functions of read, write, interrupt, address and test. Also necessary are the utilitarian commands of initialize, clear, and busy and some form of "hand-shaking" response when data are to be transferred. The system should be capable of expansion beyond a single modular housing; also there must be some easy method of communicating with the outside world.

CAMAC SYSTEM

Late in 1964 some of our European colleagues took advantage of the experience with NIM, the impact of integrated circuits and the advent of small digital computers. The elimination of manual controls in favor of program control, the shrinking volume needed as integrated circuits replaced discrete components and the flexibility afforded by digital processors all pointed toward a specification for a digital data-handling system. The European Standards Organization for Nuclear Electronics (ESONE) Committee, now representing 29 European laboratories, fostered just such a scheme. There has been active collaboration with North American NIM Committee members. The CAMAC system, a modular instrumentation system for data handling,

was announced in September 1968, and preliminary specifications, published in January 1969. In March 1970 the NIM Committee endorsed the CAMAC system and recommended its implementation in the U.S. Basic specifications are listed in the report, "CAMAC, A Modular Instrumentation System for Data Handling."[3,4]

Incidentally, the word CAMAC is not an acronym, but a palindrome; it reads the same backwards as forwards, signifying that a computer interface must look in the direction of both the experiment and the computer.

HOW IS CAMAC GERMANE?

From the viewpoint of an astronomer one can ask, "What will CAMAC do for me?"

An illustrative astronomical data-gathering facility may consist of a number of input data sources which are at various times connected to a number of data processors and recorders; in like fashion data processors and recorders are fed to a number of output devices such as digital-to-analog converters, cathode-ray tube displays and XY plotters. For each input-output device connected to a processor, a separate interface unit is usually required; these are indicated by "X" in the matrix of Fig. 2. Thus, the total number of interface units required is, in general, the product of the number of input-output devices and processors. On the other hand, if a dataway is employed that is compatible with all devices, the number of interfaces required is only the sum of the number of I/O devices and processors; these are indicated by "0" in the matrix of Fig. 2.

Fig. 3 is a block diagram of an illustrative system.

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[3] Available in U.S. as Report N700 8 from Louis Costrell, National Bureau of Standards, Wash., D.C. 20234. Available elsewhere as ESONE Report EUR 4100e from Office Central de Vente des Publications des Communates Europeenes, 2, place de Metz, Luxembourg (compte cheque postal No. 191-90). Authorized translations are available in French, German and Italian.

[4] Also helpful, CAMAC Tutorial Issue, IEEE Trans. Nucl. Sci. NS-18 (2) (1971)

Data handling facilities for physics and chemistry experiments are continually changing; I expect the same is true in astronomy. If reconfiguration can be accomplished rapidly, very real advantages result. There is no such panacea as an instant system; however, as soon as a module is plugged into a crate it is instantly available to respond to software commands. For example, programs can be written to increment address locations in a crate. If a module responds, it is read out; if it does not respond, the program skips to the next address. Thus, software may be written with system expansion in mind.

Another advantage is the ability to build large data-gathering systems without the user needing to know the internal details of the individual modules; he needs to know only the function and operating parameters of each.

In addition, if a system breaks down, it is easier to restore performance by exchanging modular blocks than to try to discover the integrated circuit that is at fault. The offending module may be repaired behind the scenes by a person trained for that function.

It is important to note that CAMAC is applicable to all forms of data processing and control; CAMAC specifications may be used without license or charge by any organization or manufacturer.

DATAWAY CONSIDERATIONS

The basic building block in the CAMAC system is the plug-in module; see Fig. 4. Modules communicate to a controller connected to a dataway via an 86-pin printed-circuit connector. One of the attractive features of the module is its economy. Hardware for a basic module, less the printed circuit board, costs approximately three dollars.

A crate capable of mounting in a 19" relay rack may contain up to 25 stations or module locations; see Figs. 5 & 6. In practice, the two right-hand positions are reserved for a crate controller. Fig. 7 shows the direction of data flow between the modules and the crate controller. Twenty-four Read lines allow the parallel transfer of up to 24 bits of data between a module and its controller. In like fashion 24 Write lines allow data transfer from the controller to a module.

Modules are addressed by 24 lines - one to each station emanating from the crate controller position: these are called N lines. Addressing is thus dependent upon module location. In addition to module addressing, four binary-coded sub-address (A) lines may be decoded to provide up to 16 module sub-addresses. Five binary-coded function (F) lines allow up to 32 function codes. One half of the function codes have been assigned to define actions of modules and controllers (e.g., read a group of registers) while the other half are equally divided between future assignment and user's option.

The minimum time of a dataway operation is one microsecond; this allows operations as fast as 10^6 per second. Two timing strobes S1 and S2 are generated in sequence on separate bus lines and accompany dataway operations. The first strobe is to gate actions which do not change the level of the signals. The second strobe is used to initiate actions in which the signal level may change as, for example, in clearing a register whose output is connected to the dataway.

Service requests from the module to the controller are instituted via 24 individual interrupt (L) lines. All such activity initiated by a module must be handled through the use of the look-at-me (L) feature. The only other action a module may make is in response to specific controller commands; this response is given by the presence or absence of a single bit on the response (Q) line to indicate whether a command has been obeyed.

Logic levels have been selected to correspond to those currently used by TTL integrated circuits now generally employed internationally. Bus voltages of ± 6 and ± 24 V will accommodate in addition the use of emitter-coupled logic and discrete-component circuits where higher speeds or higher signal swings may be required.

ON-LINE, OFF-LINE OPERATION

Small data-acquisition systems often lend themselves to off-line data recording. When the turn around time between the information acquisition and the interpretation of results will permit, one may record data directly on magnetic tape or perhaps even on a teletypewriter. Analysis of the data may then be made at another appropriate location and time.

Where higher data rates are encountered or the urgency of at least preliminary data sorting or selection are required, computations can be made with the aid of an on-line computer.

While most CAMAC systems are designed to operate under program control, the concept does not depend upon a computer being present; off-line operation is entirely feasible.

Originally it was envisioned that single-crate systems would interface to small computers via a computer controller. Thus it would be necessary to have a controller available for each crate as well as each type of computer. Along these lines M. G. Strauss, et al, Argonne National Laboratory[5], are developing systems whereby the controller in each crate serves as an interface between the computer I/O bus and the CAMAC dataway; up to 14 individual crates can be addressed by a single computer in addition to a teletype and other peripheral devices.

BRANCH HIGHWAY

As the CAMAC concept has evolved, less interest has been evidenced in computer controllers dedicated to interfacing a single crate to a specific computer. Instead a "Branch Highway" has been developed to link one or more crates (and their controllers) to a computer. Fig. 8 shows a block diagram of a CAMAC branch highway. In this manner a system exceeding the capacity of a single crate can easily be expanded into additional crates. The branch highway can extend operation up to a maximum of seven crates. (Beyond that multi-branch operation is possible, and some multi-branch systems are already being designed). In actual practice the branch highway is a 66-pair cable containing all the necessary timing, control and

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5. IEEE Trans. Nucl. Sci. NS-18 (2), 46 (1971)

data lines for branch operation.

The crate controller is now a universal device dedicated to servicing the requests of modules, passing these requests on the branch highway to the computer as well as relaying computer instructions back to the modules.

The branch highway interfaces a computer via a device termed a Branch Driver; it is specifically designed to relate branch operation to the I/O structure of a given computer. Simple branch drivers operate only on the programmed I/O computer input, more advanced units operate on either the programmed I/O or direct memory access inputs and other branch drivers operate on both modes.

Specifications for branch highways are outlined in ESONE Report "Organization of Multi-Crate Systems, Specifications of the Branch Highway and CAMAC Crate Controller Type A," EUR 4600e.[6]

BRANCH OPERATION

The physical length of the branch highway is limited, the upper limit being primarily dependent upon noise pickup and line drops. These factors can be alleviated by the use of balanced lines and cables of sufficiently low IR drop.

The branch highway has two modes of operation: In the command mode it operates as an extension of the dataway outside the crate, that is, most of the lines in the branch then perform functions similar to those in the crate. However, when not in the command mode these same lines are available for interrupt requests; "look-at-me" signals from any part of the branch typically request that a particular sequence of commands take place. The demand-handling features of the branch highway provide a means for communicating

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6. Available in U.S. from Louis Costrell, Nat. Bureau of Standards, Wash., D.C. 20234. Available elsewhere from Office Central Vente des Publications des Communates Europeenes, 2 place de Metz, Luxembourg

service requests through the branch driver to the computer; with 24 lines available one can employ up to 24 priority graded interrupt requests. This second mode is called the graded look-at-me mode or graded-L mode. In addition to this multilevel interrupt feature a single Branch Demand (BD) line indicates the presence of one or more demands on the 24 graded-L lines. Information transfers in either the command mode or the graded-L mode are appropriately interlocked and take transmission delays into account.

The individual module and crate functions shown in Fig. 7 are sent through the branch driver to and from the computer. The 24-read and 24-write dataway lines in the crate are now combined into one set of 24 read-write branch (BRW) lines. In the graded-L mode they also double as 24 interrupt lines, as described above.

Seven crate addresses have been specified with one line going to each crate. Timing of all the transfers is controlled by branch transfer signals. These allow transfers involving both single- and multiple-crate operations.

SOFTWARE

While most scientists use programs that either they have written or are provided by a commercial computer organization, CAMAC Committees in both the U. S. and Europe are meeting to consider the feasibility of CAMAC software that would be suitable for a number of small computers.

HARDWARE

It is appropriate to give a progress report of the acceptance and availability of CAMAC components at this time. Two companies in the U. S. are fabricating crates and module hardware. At least three other companies are exporting these items from Europe. To date more than 800 CAMAC crates and hardware for approximately 20,000 modules have been delivered in the U. S. At least five companies will offer CAMAC power supplies.[7] Three manufacturers are constructing A-to D and D-to A converters, scalers and related data-handling modules. At least thirty-one other companies are manufacturing CAMAC instrumentation or components in Europe.

One manufacturer in the U.S. and five in Europe are offering the Crate Controller, Type A used in conjunction with the Branch Highway.

Among U.S. and European laboratories and manufacturers, engineers have designed and are manufacturing branch drivers for the HP 2114, 2115, and 2116, PDP-8, -9, -11, -15 and the Nova and Super Nova and Sigma 3 computers. CAMAC systems are now operating in five of the National Laboratories in the U.S.; two more National Laboratories will have CAMAC systems in use shortly. Extensive plans for its use are being laid at the TRIUMF accelerator in Vancouver, Canada. Two observatories are now employing CAMAC systems: I. G. van Breda is describing the CAMAC system at the University of St. Andrews at this meeting. A. Pool[8], of the 150" Anglo-Australian telescope, reports that the CAMAC system has been adopted for instrumentation at that institution.

CONCLUSIONS

Digital data-handling systems are finding wide application in a number of areas of experimental research. Any system will be partially obsolescent before it is widely employed. However, a great deal of study and planning on both sides of the Atlantic has gone into CAMAC. Those installations and experimenters who take advantage of this program by sharing in the development and implementation of systems can expect substantial savings in return.

ACKNOWLEDGMENT

I thank Louis Costrell, Fred Kirsten, and Lee Wagner for a number of discussions on the utilization of the CAMAC concept.

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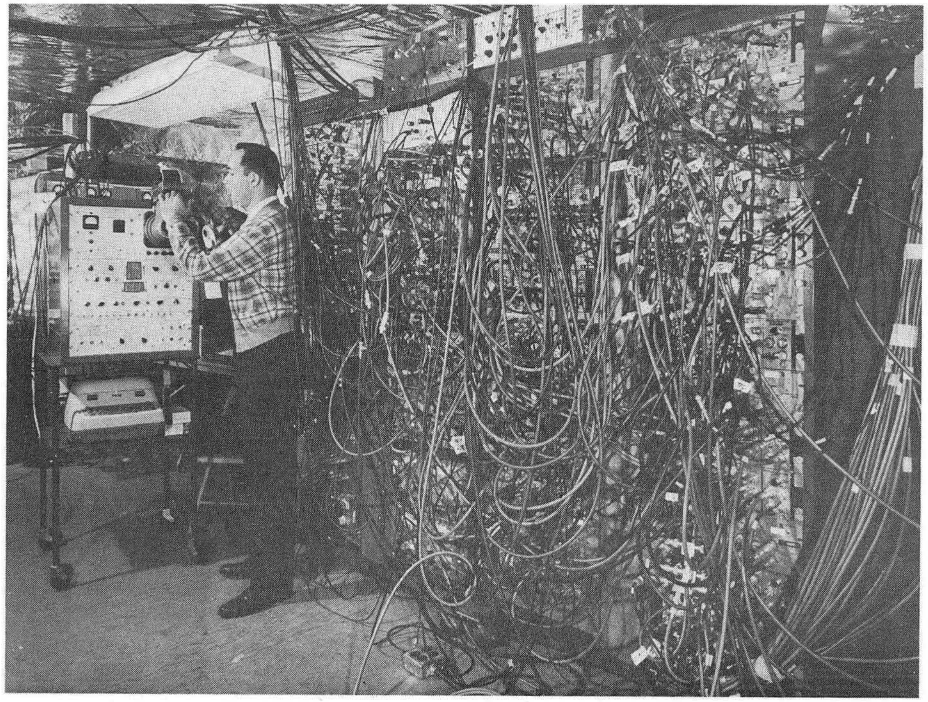
[7] "Specification for a Typical CAMAC Power Supply," Dick A. Mack and Lee J. Wagner, Lawrence Berkeley Laboratory, Berkeley, CA. 94720

[8] Private communication



Elec 3091

Fig. 1. Nuclear instrumentation (c. 1963).

NUMBER OF INTERFACE UNITS REQUIRED BETWEEN I/O DEVICES AND COMPUTER/RECORDERS	COMPUTER A	COMPUTER B	COMPUTER C	MAG. TAPE TRANSPORT A	MAG. TAPE TRANSPORT B	INCREMENTAL TAPE TRANSPORT	TELETYPE
INPUT DEVICES							
ANALOG-TO-DIGITAL CONVERTER A	⊗	X	X	X	X	X	X
ANALOG-TO-DIGITAL CONVERTER B	⊗	X	X	X	X	X	X
SCALER	⊗	X	X	X	X	X	X
SHAFT ENCODER REGISTER	⊗	X	X	X	X	X	X
X-Y POSITION REGISTER	⊗	X	X	X	X	X	X
FIXED DATA ENTRY	⊗	X	X	X	X	X	X
CLOCK	⊗	X	X	X	X	X	X
OUTPUT DEVICES							
DIGITAL-TO-ANALOG CONVERTER	⊗	X	X				
CRT DISPLAY	⊗	X	X				
LIGHT DISPLAY	⊗	X	X				
STEPPING MOTOR CONTROL	⊗	X	X				
RELAY CONTROL	⊗	⊗	⊗	○	○	○	○

Fig. 2. Number of Interface Units Required between I/0 Devices and Computer/Recorders (see text).

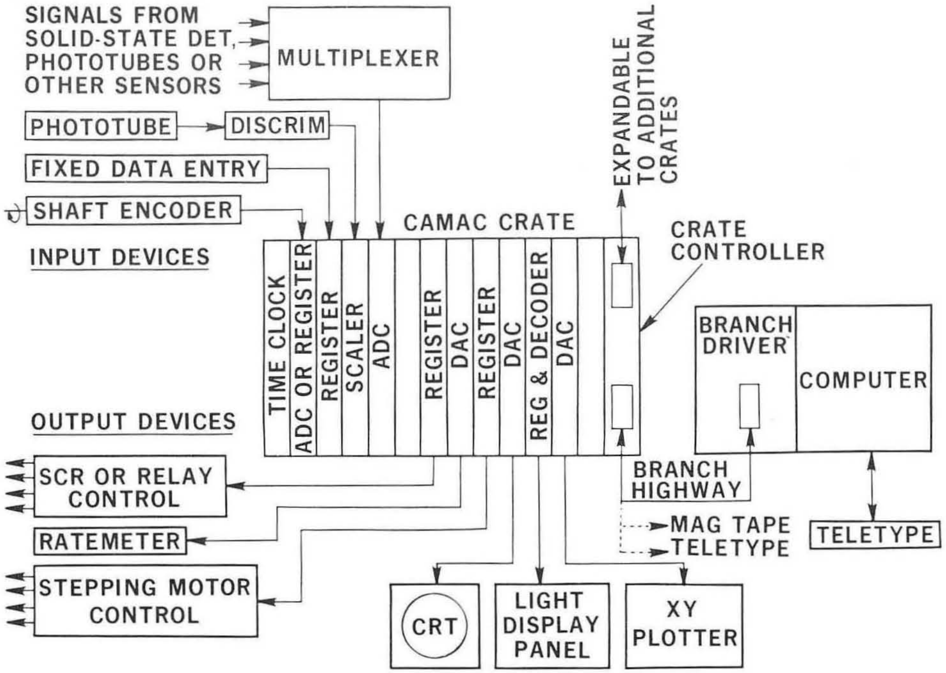
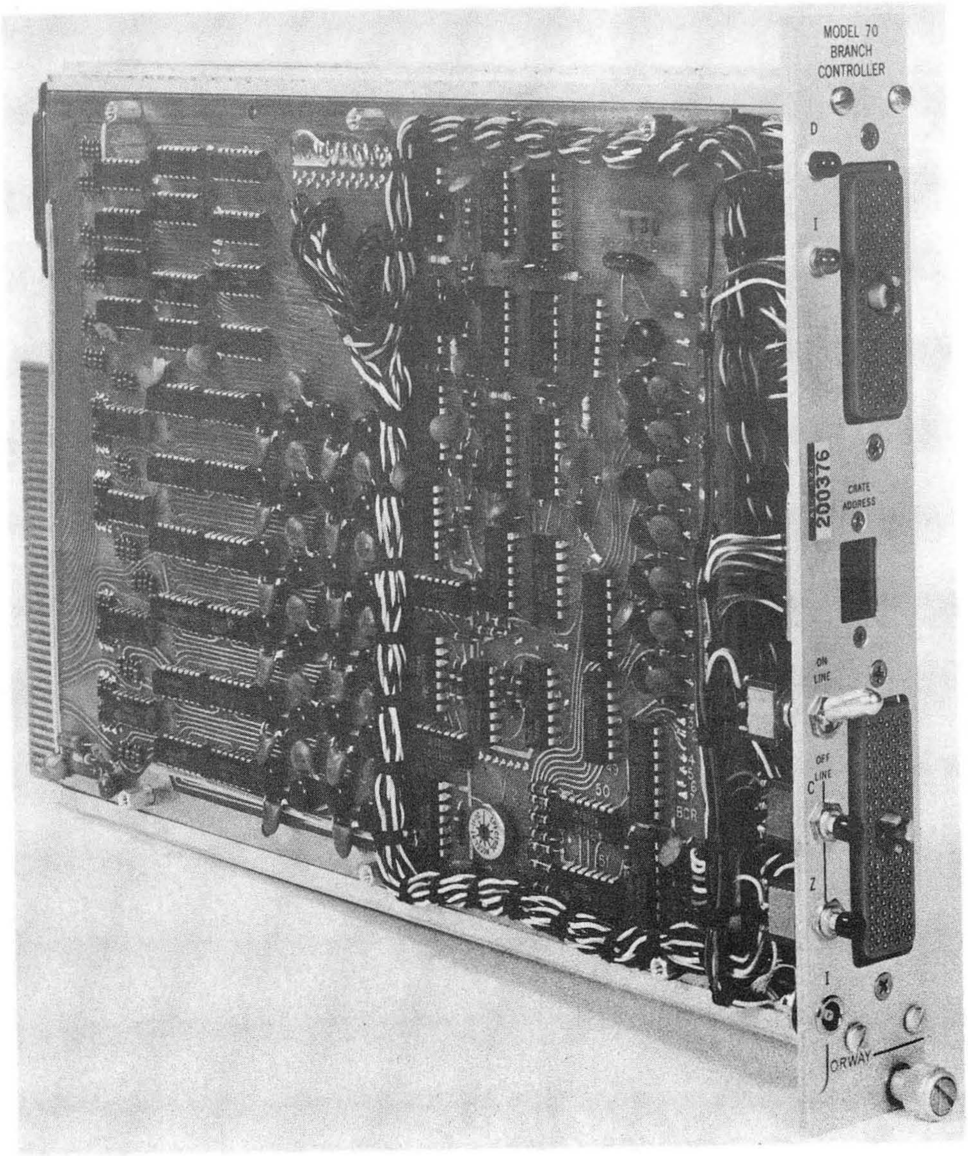


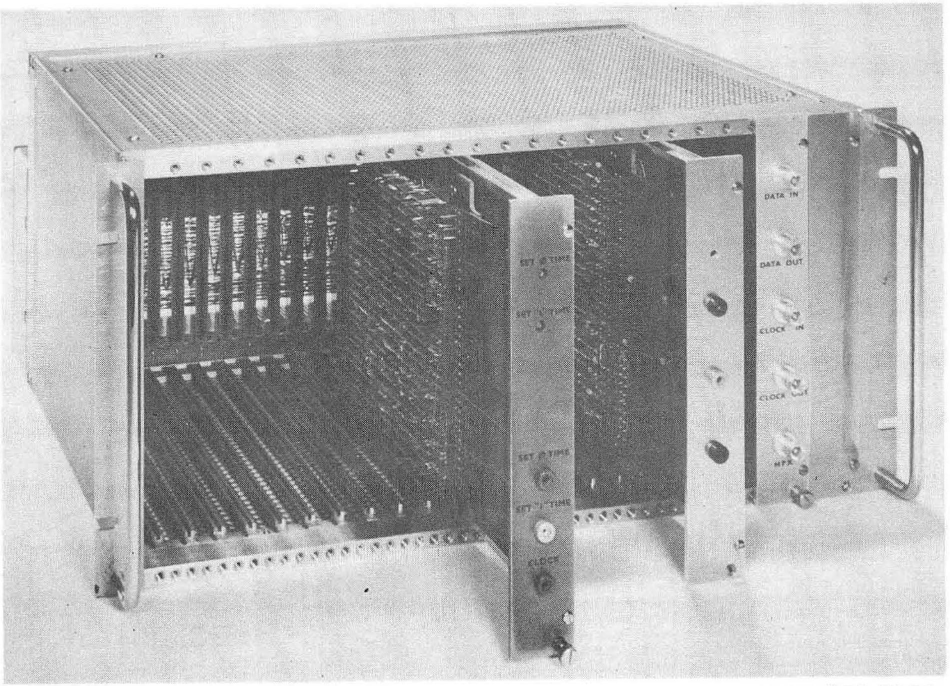
Fig. 3. Typical CAMAC System.



XBB 718 3952

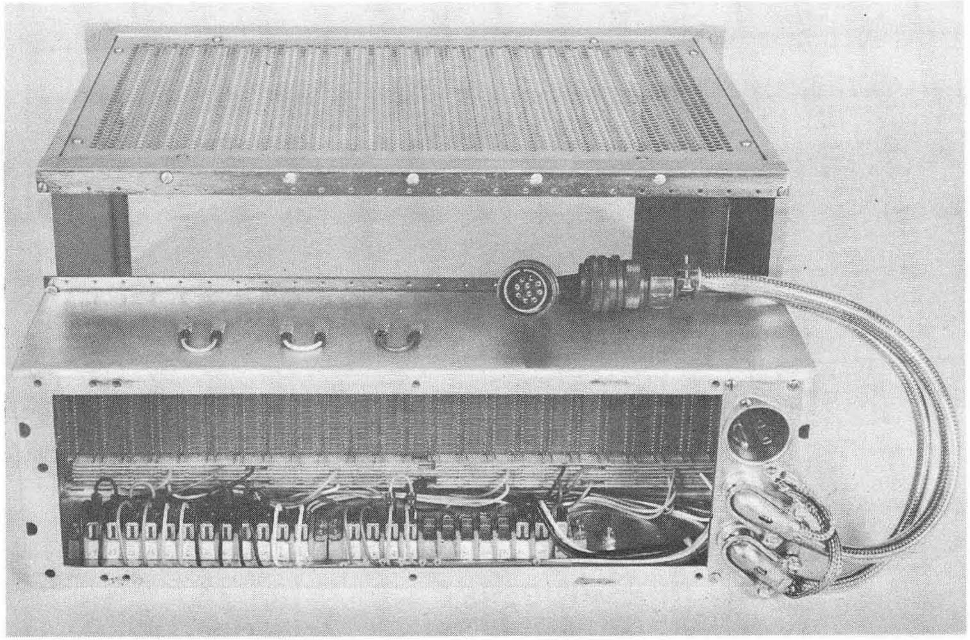
Fig. 4

A CAMAC Module



CBB 699-5884

Fig. 5. CAMAC Crate, Front View



CBB 708-3546

Fig. 6. CAMAC Crate, Rear View

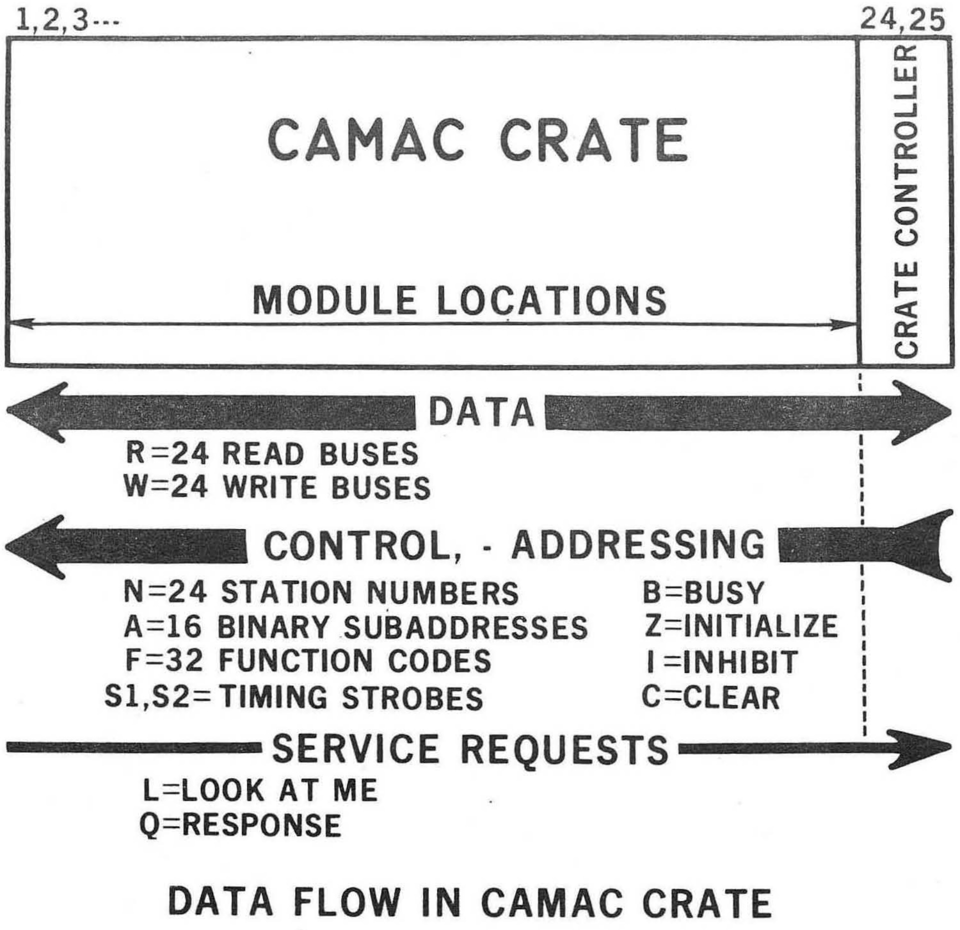


Fig. 7. Data Flow in CAMAC Crate.

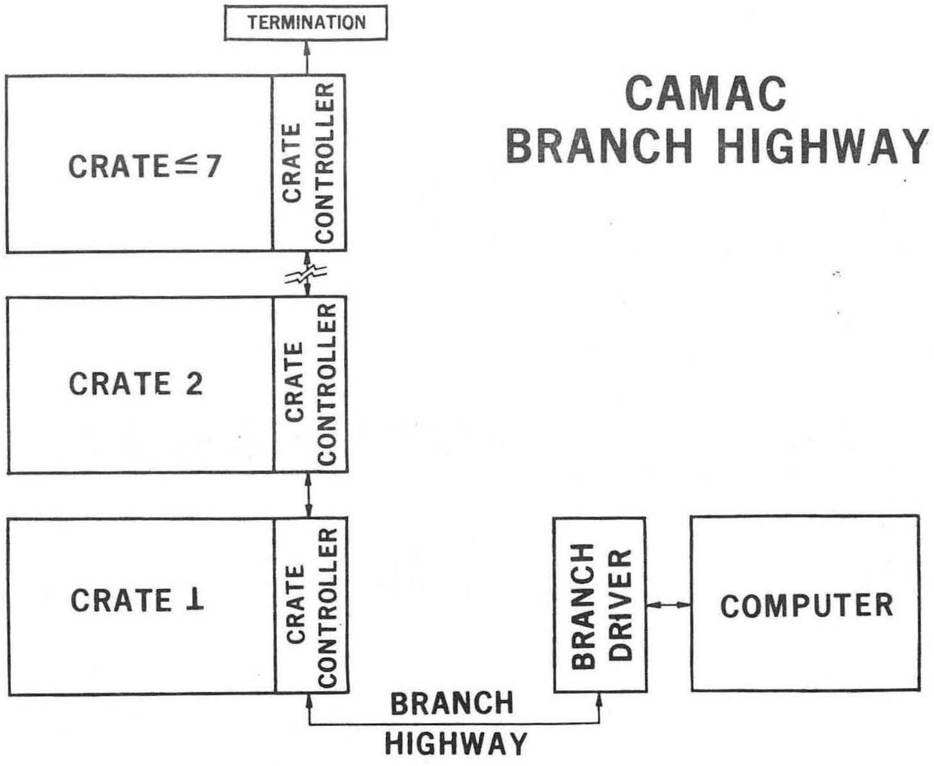


Fig. 8. CAMAC Branch Highway.

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