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University of Manitoba, Winnipeg
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CAMAC, A STANDARD FOR DIGITAL DATA HANDLING

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ABSTRACT

In the laboratory the interfacing of digital data sources to various data processors, computers, and recorders is a difficult and expensive problem. Frequent reconfiguration of data-gathering systems to meet new experimental requirements further complicates the situation. A great deal of study has gone into methods of effectively constructing as well as modifying these systems.

The CAMAC standard provides a means of interconnecting a number of data-handling devices via a common dataway. Specified by the European Standards Organization for Nuclear Energy (ESONE) and endorsed by the Nuclear Instrument Module (NIM) Committee, the CAMAC System is now available for laboratory application.

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*Work done under auspices of the U. S. Atomic Energy Commission.

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PROBLEM

The Berkeley Laboratory currently has at least 13 different models of computers manufactured by seven different companies, ranging from PDP-8's to CDC 6600's; in the future we hope to acquire even less sophisticated data processors than the PDP-8, and negotiations are under way for a machine with several times the computing capability of the 6600.

Some of the PDP-5 and -8 installations have peripherals which are more costly than the computer; on the other hand, one of our 6600's can be addressed via a device as simple as a remote teletype keyboard. Thus, in ours as well as in other laboratories, it is difficult to ascribe a common denominator to computer systems. There are many functions, however, common to a large number of data-acquisition systems so that it is not necessary to redesign from first principles for each system.

In the commercial data-handling field the lack of uniformity is even greater. The 1970 Electronics Engineers' Master Catalog lists 68 companies manufacturing integrated-circuit logic cards; no doubt this list is far from complete.

In general, each manufacturer supplies proprietary logic cards for designers wishing to augment the I/O channel on their particular computer.

As Fred Kirsten of our Laboratory has pointed out, "The data-bussing 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 widespread acceptance and momentum to make it a practical candidate for alleviating the compatibility problem." [1] Granted that you may make specifications,

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

how do you establish interface standards so that they do not reduce performance to the lowest common denominator of your computer selection? This is our dilemma!

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 from the use of the Nuclear Instrumentation Module (NIM) system. The NIM Committee was organized early in 1964, specifications were introduced by the summer of 1964, and first commercial components were displayed at the New York 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. Beginning in 1969, NIM components were extensively employed in a high-energy physics experiment at Serpukhov. The NIM program, however, with few exceptions has been largely restricted to nuclear instruments; there has been little standardization in the areas of data logging and process control.

Now let us consider the advantages of instrumentation standards. One is the availability and mass production of economical hardware of known capability. Most experimenters would be embarrassed to admit to the amount of time their technicians 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 do this in a similar fashion 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-digital converters or coincidence 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 would be capable of integration into larger systems that have not yet been contemplated.

Another point, visiting experimenters to laboratories such as CERN, BNL, and LRL have made 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.

Discussion of the data handling for experiments at the National Accelerator Laboratory and the Los Alamos Meson Physics Facility are well under way. It is clear that standardization in data handling among the universitites and national laboratories must be realized if meager equipment budgets are to be best utilized.

Any standard is admittedly arbitrary; however, one should consider: What are the minimum requirements for a data-handling system? A standard needs a read-write dataway of at least 16 lines, 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. The system should be capable of expansion beyond the units that may be housed in a single bin or crate, and 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 impact of circuit integration and the small digital computer on the world of measurement and control. Elimination of manual controls in favor of program control, shrinking volume requirements as integrated circuits replace discrete components, and flexibility afforded by digital processors all pointed toward a specification for digital data handling. The European Standards for Nuclear Electronics (ESONE Committee), representing 26 European laboratories, fostered just such a scheme. There has been active collaboration with their North American NIM counterparts. The CAMAC system, a modular instrumentation system for data handling, was announced in September 1968. Preprints of the complete specification were published in January 1969. In March of this year the NIM Committee endorsed the CAMAC system and recommended its implementation.

Incidentally, the system was first called JANUS, but this term turned out to have a prior copyright. The Committee then coined the word CAMAC, which 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.

From the viewpoint of experimentalists we can ask, "Why is CAMAC good for me?"

A typical laboratory data-gathering facility consists of a number of 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 readout devices such as cathode-ray tube displays and XY plotters. For each input-output device connected to a processor, a separate interface unit is usually required (Fig. 1A). 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 input-output devices and processors (Fig. 1B). The resultant savings can be significant.

Experimental setups are continually changing; if reconfiguration can be accomplished rapidly, very real advantages result. There is no such panacea as an instant experiment; 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 experimenter's needing to know the internal details of the individual modules; he needs to know only function codes and program routines.

In addition, if a system breaks down, it is easier to restore performance by exchanging modular blocks than to discover the integrated circuit that is at fault.

Basic specifications are listed in "CAMAC, A Modular Instrumentation System for Data Handling,"[2] ESONE Report EUR 4100e, March 1969. A

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2. Available from Office Central de Vente des Publications des Communatés Européenes, 2, place de Metz, Luxembourg (compte chèque postal No. 191-90). The specification will also be available shortly in the U.S. from Mr. Louis Costrell, AEC Committee on Nuclear Instrument Modules, National Bureau of Standards, Washington, D.C. 20234.

companion document deals with means for interconnecting several crates to a data processor or computer. The preliminary report, entitled "Organization of Multi-Crate Systems (Specifications of the Branch Highway and CAMAC Crate Controller Type A)" is to appear as ESONE Report EUR 4600e.[3]

It is fundamental to note that CAMAC is not restricted to nuclear instrumentation, but is applicable to all forms of data processing. The system has been designed so that an assembly made up of crates and plug-in modules can be connected to an on-line digital computer by means of a unit called a branch driver. However, the use of a computer is entirely optional and the concept does not depend upon a computer's being present. The CAMAC specifications may be used without license or charge by any organization or manufacturer.

A crate may contain up to 25 stations or locations for plug-in modules with at least the two right-hand positions reserved for a controller. See Fig. 2. Modules communicate with each other via a passive multiconductor dataway. Eighty-six-pin edge-card connectors allow individual modules to plug into the dataway.

Table I shows a summary of CAMAC commands and responses. Each module is addressed by means of a single line from the crate controller position; therefore, addressing is dependent upon module location. If a module is relocated, the computer program must take this into account.

In the same fashion, a module may initiate an interrupt by means of a direct line from each module position to the controller. Separate read and write data buses of 24-bit capacity have been specified. The use of separate read and write dataways allows one to use less expensive module line drivers than would be required for a combined read-write dataway.

Originally it was envisioned that single-crate systems would interface to small computers via a computer controller. Thus it would be necessary to have one controller available for each crate as well as each type of computer. It was soon apparent that many single-crate systems would expand into those involving more than one crate. Also a good many of the controller

3. This report will be available about January 1971 from the Office Central de Vente des Publications des Communatés Européennes, and in the U. S. from the AEC Committee on Nuclear Instrument Modules.

functions for a PDP-8, for example, were common to controllers for all computers. There will be, in addition, a number of existing data-gathering or program-controlled devices that could communicate via a common dataway; however, they are not packaged in CAMAC modules. How can these be integrated into a new system being designed in CAMAC?

When autonomous operation of a single crate is required, how can it easily be effected?

The branch-highway concept described in REPORT EUR 4600e [3] provides a viable solution to all of the above problems. Figure 3 illustrates how up to seven crates may be interfaced through a branch driver to a single computer. The physical length of the branch highway is limited, the upper limit being dependent upon line drops causing a loss in signal amplitude and the delay time one is willing to allow for the appropriate response after a branch-highway data operation has taken place.

The branch highway has two methods 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. Interrupt ("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 service requests through the branch driver to the computer. With 24 lines available one can employ up to 24 different 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 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 enumerated in Table I are sent through the branch driver to and from the computer. The 24-read and 24-write dataway lines in the crate have been combined into one set of 24 read-write branch 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.

In multiple-crate operation it is imperative that the branch driver wait for a response from the most remote crate before continuing data transfer.

HARDWARE

It is appropriate to give a progress report of the acceptance and availability of CAMAC components in North America at this time. One company is fabricating crates and module hardware in the U. S.; two other companies are importing these items from Europe. To date more than 200 crates and hardware for approximately 3000 modules have been delivered in the U.S. At least two companies are offering suitable power supplies. Two manufacturers are constructing scalers and related data-acquisition modules. At least two other companies are importing CAMAC instrumentation designed in Europe.

One manufacturer in the U. S. and a number in Europe are offering the basic Crate Controller, Type A, that is used in conjunction with the Branch Highway. First deliveries are expected by late summer.

Among U. S. and European laboratories and manufacturers, engineers are designing branch drivers for the HP 2114, 2115, and 2116, PDP-15 and the Nova and Super Nova computers.

EXPERIMENTAL USE

Now that hardware is available, where will it be employed? What are the recommendations for its application? Early use of CAMAC at the laboratories involved one-of-a-kind devices and systems. Some of these at Berkeley included a disk controller, a PDP-5 interface, and magnetic-tape controllers.

At SLAC 96 channels of amplifiers and registers were built in CAMAC hardware for the readout of a multiwire proportional chamber.

At Argonne an interface controller for a MAC-16 computer is under development.

A joint NAL-Yale hyperon-decay experiment is being instrumented for running at Brookhaven this fall. It will use 250 spark-chamber scalers, 24 counter scalers, and 6 ADC's plus latches. These modules, housed in three CAMAC crates, interface with a PDP-15 computer.

A good example of a CAMAC compatible system is the 100-MHz scaler system specified jointly by our Laboratory and SLAC and developed by two commercial companies. See Fig. 4. Twenty-four-bit 100-MHz scaler modules are in production by one manufacturer and will be available from another by September. Four scaler channels housed in a single-width module will cost approximately $250.00 per channel.

Two modes of readout will be available at the same time. Visual readout of a TV monitor will allow the experimenter to display the contents of 2, 4, 8 or 16 scalers simultaneously. The display information can be updated almost continuously. At the same time a readout adaptor will allow the scaler contents to be fed to an existing interface for block transfer into a PDP-9 computer. As CAMAC systems become more prevalent, the readout adaptor will be replaced by a type A crate controller feeding a CAMAC branch highway.

An interesting command structure allows the two readout systems to each operate autonomously and asynchronously.

CONCLUSIONS

The problem of finding a common denominator for digital data-handling systems in nuclear research has no easy, ready-made solution. 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 laboratories 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.

FUNCTIONS WITHIN CAMAC CRATE

SYMBOL	OPERATION	M CC	USE
N	STATION NUMBER	←	CRATE CONTROLLER CAN SELECT INDIVIDUAL MODULES #1 TO 24.
L	LOOK AT ME	→	EACH MODULE CAN INTERRUPT CRATE CONTROLLER.
A	SUBADDRESS	←	ALLOWS 16 SUBDIVISIONS (E.G., SCALERS) OF EACH MODULE.
F	FUNCTION	←	32 DIFFERENT FUNCTION CODES AVAILABLE.
R	24 READ LINES	→	DATA FROM MODULE TO CONTROLLER.
W	24 WRITE LINES	←	DATA FROM CONTROLLER TO MODULE.
B	BUSY	←	BUSY.
I	INHIBIT	←	INHIBITS ANY ACTIVITY DESIRED.
C	CLEAR	←	CLEARS FLIP FLOPS, REGISTERS, ETC.
S	STROBE	←	TWO TIMING STROBES FOR DATA TRANSFER.
Q	RESPONSE	→	ARE YOU THERE?
Z	INITIALIZE	←	SETS UP INITIAL CONDITIONS.

LEGEND:

M = MODULE

CC = CAMAC CRATE

M → CC INDICATES COMMUNICATION FROM MODULES TO CRATE CONTROLLER.

M ← CC INDICATES COMMUNICATION FROM CRATE CONTROLLER TO MODULES.

TABLE I

	COMPUTER A	COMPUTER B	COMPUTER C	COMPUTER D	COMPUTER E	COMPUTER F	COMPUTER G	COMPUTER H	COMPUTER I	MAGNETIC TAPE	INCREMENTAL TAPE	TELETYPE
INCOMING DATA												
DATA REGISTER	X	X	X	X	X	X	X	X	X	X	X	X
SCALER	X	X	X	X	X	X	X	X	X	X	X	X
FIXED DATA	X	X	X	X	X	X	X	X	X	X	X	X
SPARK CHAMBER DIGITIZER	X	X	X	X	X	X	X	X	X	X	X	X
PROPORTIONAL CHAMBER R/O	X	X	X	X	X	X	X	X	X	X	X	X
ANALOG TO DIGITAL CONVERTER	X	X	X	X	X	X	X	X	X	X	X	X
CLOCK	X	X	X	X	X	X	X	X	X	X	X	
OUTGOING DATA												
CONTROL REGISTER	X	X	X	X	X	X	X	X	X			
DIGITAL TO ANALOG CONVERTER	X	X	X	X	X	X	X	X	X			
CRT DISPLAY	X	X	X	X	X	X	X	X	X			
LIGHT DISPLAY	X	X	X	X	X	X	X	X	X			
XY RECORDER	X	X	X	X	X	X	X	X	X			

FIG. 1A

NUMBER OF INTERFACE UNITS USUALLY REQUIRED BETWEEN INPUT AND OUTPUT DATA DEVICES AND COMPUTERS OR RECORDERS

	COMPUTER A	COMPUTER B	COMPUTER C	COMPUTER D	COMPUTER E	COMPUTER F	COMPUTER G	COMPUTER H	COMPUTER I	MAGNETIC TAPE	INCREMENTAL TAPE	TELETYPE
INCOMING DATA												
DATA REGISTER	X											
SCALER	X											
FIXED DATA	X											
SPARK CHAMBER DIGITIZER	X											
PROPORTIONAL CHAMBER R/O	X											
ANALOG TO DIGITAL CONVERTER	X											
CLOCK	X											
OUTGOING DATA												
CONTROL REGISTER	X											
DIGITAL TO ANALOG CONVERTER	X											
CRT DISPLAY	X											
LIGHT DISPLAY	X											
XY RECORDER	X	X	X	X	X	X	X	X	X	X	X	X

FIG. 1B

REDUCTION IN NUMBER OF INTERFACE UNITS REQUIRED WHEN DATA HIGHWAY IS EMPLOYED

XBL 708-1667

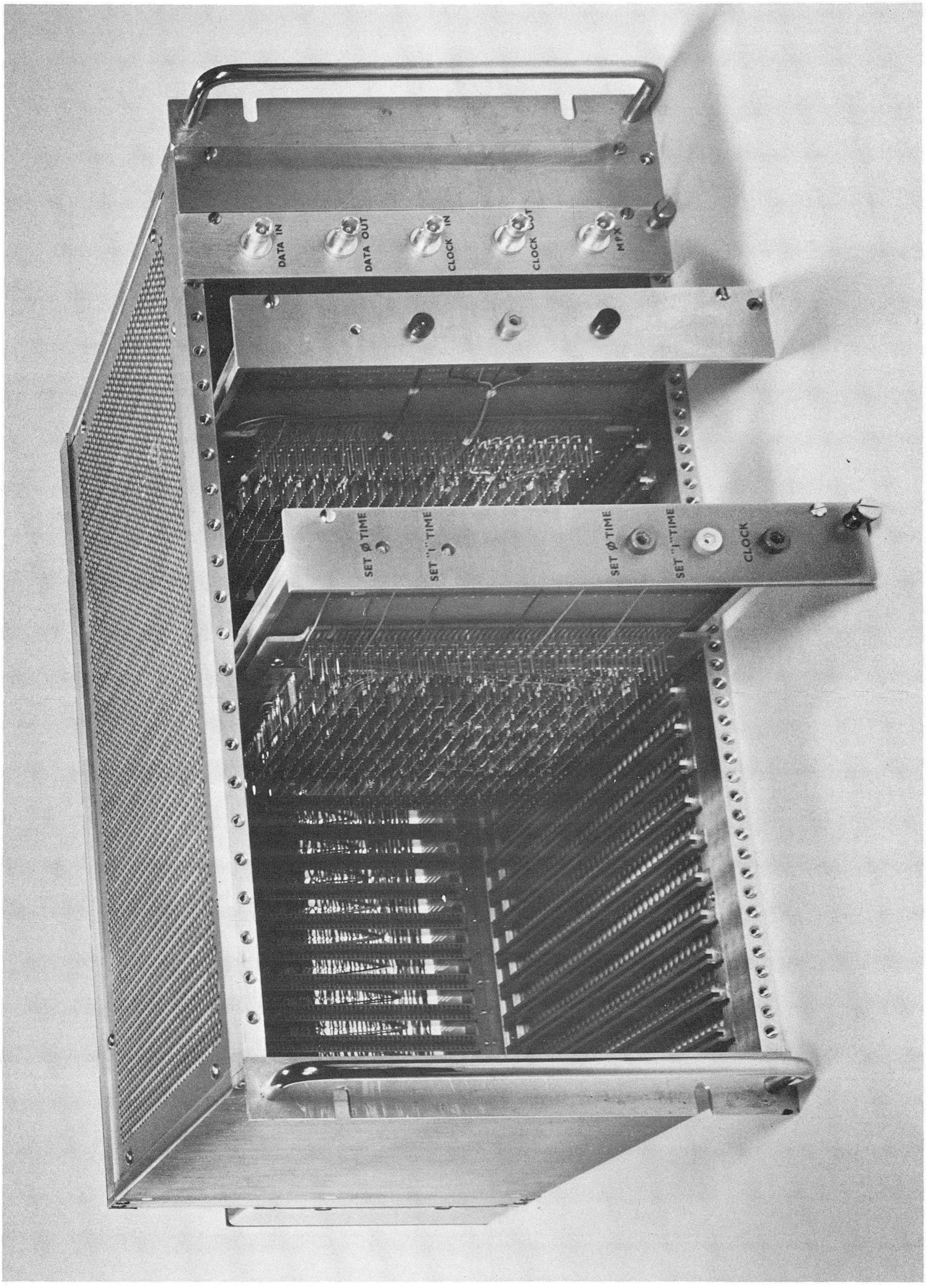

FIG. 2. CAMAC CRATE

CBB 699-5884

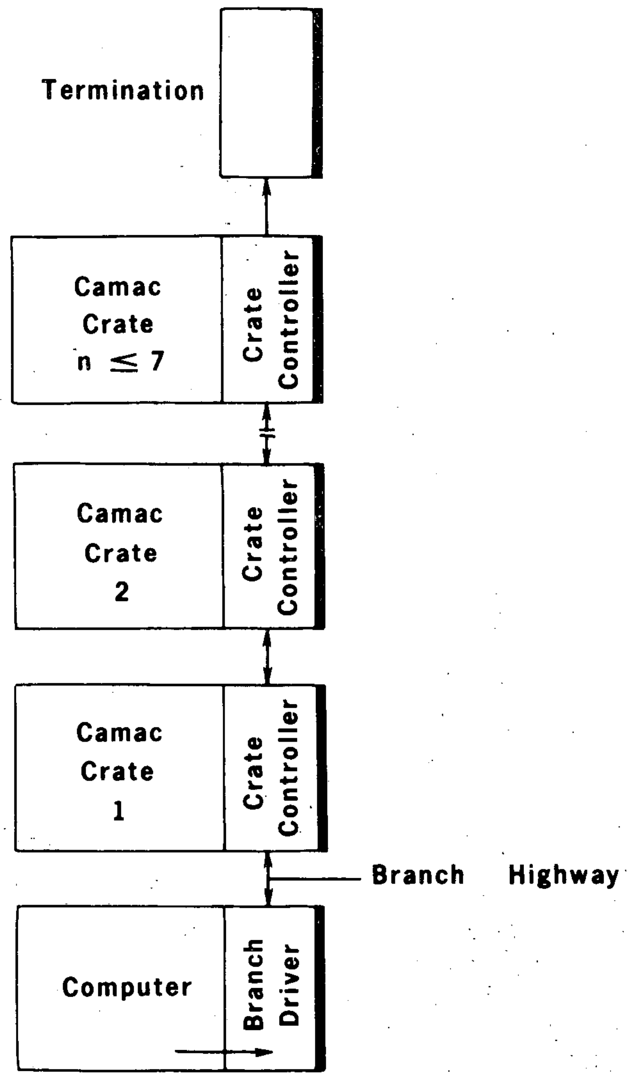

FIG. 3

METHOD OF INTERFACING
ONE OR MORE CRATES TO A COMPUTER

XBL 708-1668

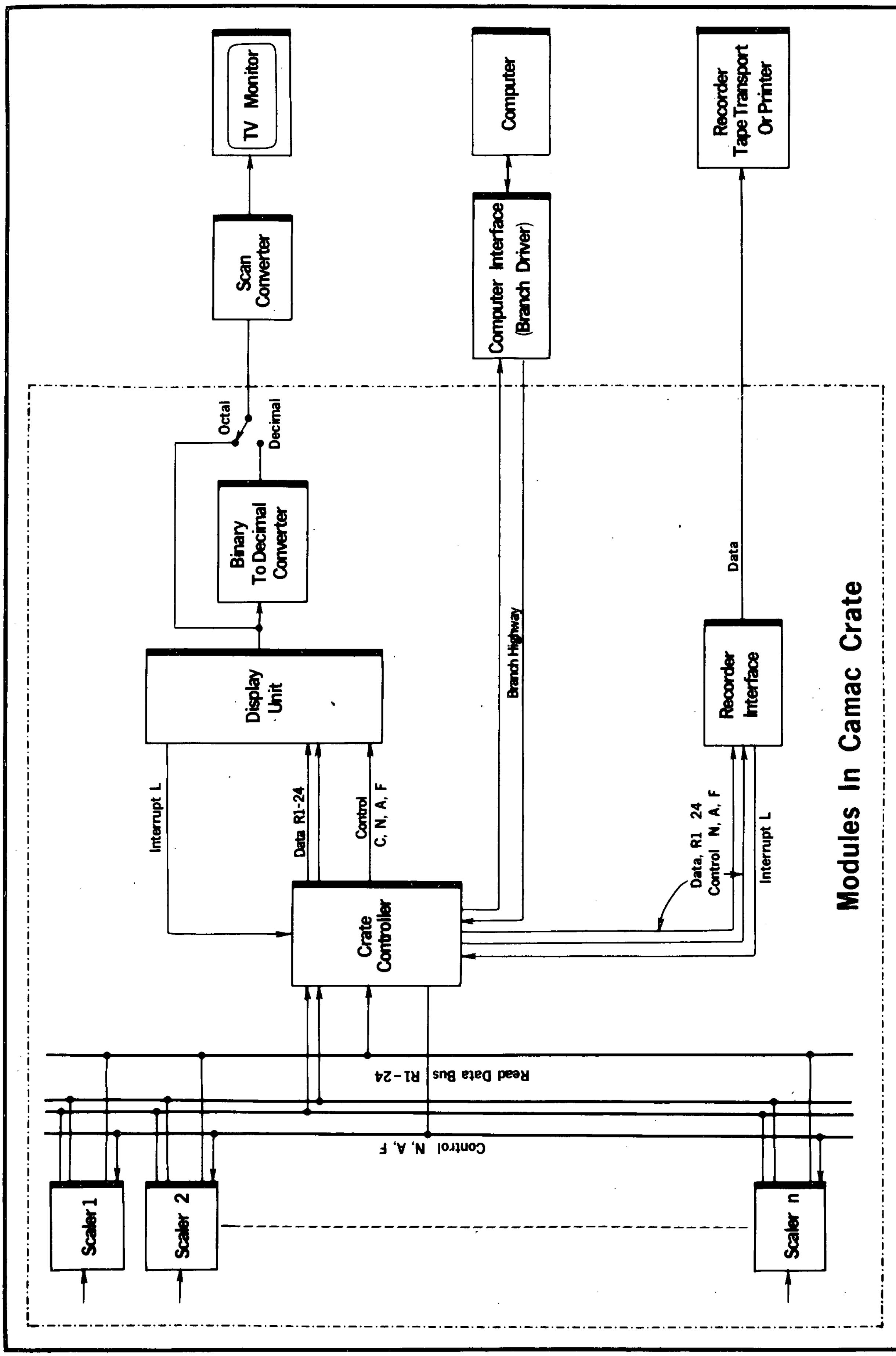

FIG. 4

CAMAC COMPATIBLE SCALER SYSTEM

XBL 708-1669

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