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CAMAC-A NEW IEEE MODULAR DIGITAL INTERFACE STANDARD

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1. Introduction

Standardization has not always been a powerful force in electronics. However, recently the IEEE has adopted two standards in the area of digital interfacing, a field where great potential benefit exists in standardization. The first, IEEE STD-488-1975, provides a standardized interface for programmable instruments and has been described in previous Spectrum articles. The second, IEEE STD-583-1975, commonly called CAMAC, is an established modular digital interfacing standard, particularly appropriate for computer oriented data and control systems. Prior to its adoption by the IEEE it was adopted by IEC and has had widespread application over the past six years in laboratories, and more recently in industrial process control. The purpose of this article is to acquaint practicing system engineers with the basic principles and applications of the CAMAC standard, and additionally to give an insight into how this standard can benefit the digital community as a whole.

Future articles will cover more complex aspects and recent developments of the standard.

2. Background, History, Organization

The origins of this standard go back over ten years when a modular instrumentation package--Nuclear Instrument Module (NIM)--was standardized for nuclear electronics. This standard was developed by a user group in the United States headed by Mr. Louis Costrell of the National Bureau of Standards, and included standardization of the package, the power supply voltages, and interconnection signal levels. NIM modules were similar to several commercial packages, but were essentially independent of any particular one. The benefits of module interchangeability became immediately obvious to the laboratory community, and at the present time much of the nuclear electronics throughout the world is packaged in NIM, and is

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completely interchangeable. Thus the benefits of modular standardization became a reality.

Several years after the introduction of the NIM standard, the community of laboratories in Europe--European Standards on Nuclear Electronics (ESONE)--saw the need for a modular standard such as NIM but which also included a high speed general purpose digital transmission standard, since the significance of on-line digital computers in experiments had since become established. The result was the modification of the NIM standard packaging to include a standardized mechanism for digital data transmission between the modules. This new expanded standard, called CAMAC, was first published in Europe in 1969 and was endorsed by the United States NIM Committee in 1970. It is important to point out that, although this standard was developed by a group of laboratory instrumentation personnel, the goal was a generalized digital standard, appropriate for all applications involving transfer of digital data.

Since the first document was published in 1969, the ESONE and NIM groups have collaborated on further development of the standard, and the current CAMAC standard includes several compatible documents from which the designer can select configurations to fit the particular needs of his application. No matter what combination of documents is selected the same modules are usable, and complete system compatibility is assured.

The original NIM group (supported by ERDA) meets regularly in the United States or Canada (it includes representatives from Canada) and the ESONE group meets in Europe. In most cases a liaison member from each group is present at the meetings. Although these organizations basically consist of laboratory representatives, they are now being supplemented by industrial representation. In the United States there is now a CAMAC Industry Applications Group (CIAG) which is particularly interested in using CAMAC for process control, and in Europe there is a European CAMAC Association representing widespread user groups in many diverse areas of application.

Thus the inherent generality of the CAMAC standard has inspired much broader usage, and it is now being used in medical research, astronomical research, industrial process control, as well as in many other applications. There are now some 70 companies throughout the world offering CAMAC products, and an impressive array of functional modules and systems components now exists.

All elements of the CAMAC standard are non-proprietary, and there is no license or royalty associated with the use or sale of CAMAC products.

3. Why Have a Modular Standard?

By now the significance of digital computers has been well established. They are widely used for business data processing, scientific data processing, and to a rapidly increasing degree for real time monitoring, data logging, and control of scientific experiments and industrial processes. In this latter area--that of real-time use--the computer system must be electrically connected to physical processes in the real world via various transducers or interfaces. The nature of these interfaces depends primarily on the nature of the physical process involved. On the other hand, the interface must also relate to the computer via an I/O bus, or computer port.

An efficient way to handle connection of computers to the real-time process is via a universal modular interfacing method whereby interfaces to physical processes can be designed and built independently of any particular computer I/O port or packaging method as shown in Figure 1. The efficiency of this approach can be readily appreciated if one takes the example of a 14 bit A-to-D converter. Using a computer independent interface standard only one such module need be designed and produced for the entire spectrum of computers. Without the standard a distinct A/D sub-system has to be designed and packaged for each computer--with no improvement in performance or change in function. The benefits to the whole computer system community, both users and producers, are considerable.

The implications of this approach should be considered. By its very nature modularity has a whole range of benefits in computer systems. First is rapid system modification to meet new demands. Another is independent testing of functional modules before they become part of a complex system; this can save valuable system checkout time. Another is improvement in maintenance--modules can be rapidly exchanged to minimize system down-time.

If we add standardization to modularity, the benefits broaden considerably. The main advantage is illustrated by the example of the 14 bit A-to-D converter mentioned previously. There need be only one such A-to-D converter for all computer systems. The eventual result is larger volume, less custom engineering, and hence eventually lower price to the final user. An equally significant benefit is the wider spectrum of functional modules available to the system designer. Since many organizations are constructing compatible modules, the spectrum of products is inherently broadened. A further advantage is sharing of functional modules between systems, deferring their obsolescence, and reducing unnecessary design. This latter feature is especially attractive to larger organizations which are responsible for operation of many systems. The possibilities of central stocking, and ease of transference of functional modules between systems makes maintenance and development far more manageable for such an organization.

The primary justification for such a standard comes via connections to a real-time process. In addition, since the standard includes versatile two-way communication then the possibility exists of also connecting conventional data processing peripherals such as magnetic tape, punched tape, etc. These interface modules are then computer-independent. However, in any particular application it may be more convenient to use the manufacturer's peripheral interface, especially when this is fully software supported. Secondly, it is possible to construct special data processors in the standard format, which are computer independent. This latter feature is gaining in importance with the rapid growth of microprocessors and distributed control.

The elements of the standard are (1) packaging, (2) functional, (3) electrical. Since all elements are contained in the standard, compatible computer-independent interface modules can be designed and produced, and entire systems can be synthesized from off-the-shelf modules.

4. The Basic Specification - IEEE STD-583[1]

The basis of the system is the crate or bin which houses the interfacing modules. Figure 2 is a photograph of a typical crate and modules meeting the standard. At the rear of the crate is a dataway or motherboard which provides a digital pathway between the modules (usually a printed multilayer board) through an 86 pin connector on each module. It is this dataway which is carefully standardized to ensure interchangeability of modules, yet generalized to permit all of the functions necessary for the modules to control and/or measure physical processes in the real world.

In particular, the crate contains up to 25 connectors to receive up to 25 modules. The modules may be multiple widths to accommodate varying complexities or to provide varying front panel space. What is inside the modules is not specified in any way, only the interface to the dataway is standardized. Figure 3 illustrates the nature of this interface. The single interface to the external computer, controller, or additional crates is made via a module inserted at the right side of the crate, called the crate controller, as shown in Figure 4.

With the advent of microprocessors an entire controller or computer can be housed in this crate controller, in which case there need not be an interface through the crate controller--all of the intelligence is in the crate controller itself. A commercial unit of this nature is shown in Figure 5. It is emphasized that in the basic definition of the standard the exact nature of the crate controller is not defined; only the interface to the dataway is standardized. Other documents in the CAMAC set,described in the next section, do specify several types of crate controllers that are considered "standard", but any crate controller conforming to this document will permit interchangeability of modules, a primary goal of the standard.

At the present time (Aug. 1975) the basic specification has been endorsed as IEEE STD-583. Others in the CAMAC set are currently being processed through the IEEE.

5. The CAMAC Documents and System Organizations

The CAMAC standard is actually a set of compatible documents describing several systems organizations and/or levels of compatibility. First there is the basic document[2] which standardises the crate-module pair described in the previous section; that is, adherence to this standard guarantees mechanical, electrical, and functional compatibility of the modules and the crates. Designing, building or buying a system to the specifications of this document already guarantees the compatibility of all CAMAC modules. All that is necessary is to provide an interface to a computer or controller via a specialized crate controller. Many such systems are in use, and dedicated crate controllers (designated Type U) are commercially available for most popular minicomputers. This specification, along with a supplement[3] comprise IEEE STD-583.

A second component of the set is the parallel branch highway[4] published in March 1972 which describes a standardized approach to the interconnection of 7 crates as shown in Fig. 6. This "branch" is computer independent and completely versatile; thus standard computer independent crate controllers can be developed to be compatible with this branch. Such crate controllers, specified in the document as Type A-1 crate controllers, are commercially available from many sources (Fig. 7) and are completely interchangeable. In order to connect the branch to a minicomputer, an interface (branch driver) is necessary.

The parallel branch highway provides a standardized way of interconnecting crates via a high-speed, completely parallel link. It is one of the important options available to the system designer. However, other ways of connecting crates may become attractive in certain applications. No matter in what manner the crates are connected the same <u>modules</u> remain compatible.

In fact, it became apparent that interconnection of CAMAC crates via serial transmission links would offer a powerful option to the system designer interested perhaps in slower data transfers, but with considerable distances between crates. A CAMAC document published in December 1973[5] describes a serial interconnection of up to 62 crates, based on a unidirectional loop (Fig. 8) which may be independent of the parallel branch highway. Serial crate controllers compatible with the document have been specified and designed which are completely interchangeable. Crate controllers of this type, termed SCC-L1 (Fig. 9), as well as serial system driver modules, are commercially available.

Serial communication based on the new balanced EIA standard RS-422 is specified, but other forms of serial communication between crates are of course possible. In fact, at the Atlantic Richfield Hanford Laboratories, crates communicate via a two-way laser link over two kilometers. The serial method of interconnection has been of particular interest to industrial users in the field of process control since it is well suited to communication and control within a large industrial process plant.

Another element of the CAMAC standard, that of software standardization, has been published[6] in January 1975 which gives users a common language to be used when dealing with CAMAC systems. This document describes the "IML language" as a guide for those implementing languages and operating systems who wish to make CAMAC input/output available to users. Both the Branch Highway and Serial System are supported.

Still another element of CAMAC is the specification published for analog signals[7], in order to achieve compatibility between analog signals handled by CAMAC modules. The specification covers only single ended 50 ohm systems, and thus is not meant to cover all industrial applications. Guidelines for the latter are being developed.

6. CAMAC Products

As of the end of 1974, the CAMAC Bulletin listed approximately 70 CAMAC manufacturers throughout the world, predominantly in Europe. The smallest of these are essentially component or single-product manufacturers, while the largest are companies which are beginning to offer some level of complete systems support, at least in limited areas of application. An abbreviated list of types of available products is shown in Table I.

At the present time the types and variety of components and subsystems available in the U.S. are increasing rapidly in response to stimuli from users. Most manufacturers will respond rapidly to demand for new items, especially functional modules, which often are developed in direct response to user specifications. For example, modules such as stepping motor controllers, synchro controllers, and I/O modules with relay or optical coupler isolation have recently been generated in response to user requests from the process control industry. Because of the standard packaging and data bus inherent in CAMAC, development costs for new functional modules are minimal.

The functional listings shown are necessarily brief; however, it is a fact that even with the present small manufacturing base, a system engineer can configure a complete real time system for many popular minicomputers through a selection of off-the-shelf sub-systems. Further user demand will result in a greater variety of modules and sub-systems, and greater economies through market competition.

A partial list of U.S. manufacturers of CAMAC equipment is found at the end of this article.

7. Some Typical Applications

CAMAC has been implemented in a broad range of applications and at a variety of levels, from stand-alone sub-systems to complete real-time computer control systems. Due to the history of CAMAC most of the existing applications are in a nuclear laboratory environment. However, with the development of the standard serial system, industrial or commercial users have now realized the potential benefits of such a standard and industrial applications have been initiated and developed.

Industrial Process Control

A large process control system has been recently implemented by the Aluminum Company of America (ALCOA) at their Warrick, Indiana plant. This system consists of 23 crates controlling 45 industrial furnaces, with each crate housed in a NEMA 12 enclosure. It features a serial highway with a backup loop operating over coaxial cable at a 1 megabaud data rate, with clock and data transmitted over the same cable. The serial highway employs Type L-1 serial controllers, and is driven from a ModComp II computer with a completely redundant backup computer and automatic I/O switchover. Conventional computer peripherals are interfaced via the computer manufacturer's hardware and software. The system operates in a direct digital control (DDC) mode. All components of the system including the serial highway driver are commercially built, and all the instrumentation modules used are second-sourced. Figures 10 and 11 show two modules for this application.

Examples of other systems in operation or under development include a computerized test facility at General Motors, Electromotive Division, and a computerized slab caster at Inland Steel. A number of other large companies are currently considering CAMAC systems.

TABLE I

ABBREVIATED LIST OF

COMMERCIALLY AVAILABLE CAMAC HARDWARE

ITEM	ITEM

1. Modules - General Purpose

   Counters
   Counters - Preset
   Timers
   Input Register - Parallel
   Input Register - Serial
   Input - Output Register
   Input Register - Isolated
   Clock Generators
   Pulse Generators
   Word Generators
   DVM Modules
   Pulse Duration Demodulator
   Output Register - Parallel
   Output Register - Serial
   Output Register - Isolated
   Stepping Motor Controller
   Output Register - Relay
   Dataway Display Module
   Look-At-Me (LAM) Grader

2. Multiplexers and Converter Modules

   Analog Multiplexer
   Sample-and-Hold Multiplexer
   Analog-Digital Converter
   Time-Digital Converter
   Digital - Analog Converter
   Synchro - Digital Converter
   Integrator - ADC
   Digital Multiplexer
   Code Converter Module

3. Peripheral Interface Modules

   Paper Tape Reader
   Card Reader
   Line Printer
   Cassette Tape Control
   TTY Control
   CAMAC-CAMAC Data Link
   Graphic Display
   Display Plotter
   Display Vector Generator
   Display Systems
   Serial I/O Register
   Buffer Memory
   Magnetic Tape Control

4. Crate Controller Modules

   Type A-1 Parallel
   Type L-1 Serial
   Dedicated Single-Crate (Type U) for:
      DEC PDP-8
      DEC PDP-11
      DG Nova
      HP 2100 Series
      Varian 620 Series
      ModComp
   Manual Crate Controller
   Autonomous or Microprocessor Single Crate Controller

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ITEM
5. <u>Branch Drivers, Extenders</u>
Parallel Multicrate Drivers For:
DEC PDP-8
DEC PDP-9
DEC PDP-11
DEC PDP-15
HP 2100 Series
Varian 620 Series
DG Nova/Supernova
Interdata 70 Series
Honeywell 316/516
Siemens 320/330, 404/3
General Automation SPC16
Microdata 800/CIP 2000
Autonomous Systems
Parallel Branch Extender
Serial Branch Driver
Serial Branch Extender
Serial Driver - Manual
6. <u>Crates and Associated Hardware</u>
Crates, Powered
Crates, Unpowered
Module Kits
Power Supplies

Laboratory Data Acquisition

The simplest implementations are those in which CAMAC is used to add on to, or substitute for part of an existing system. An example is shown in Figure 12, which shows a large time-shared machine control and multi-user data acquisition system at the Stanford Linear Accelerator Center (SLAC). Simplified CAMAC branches have been added via existing multiplexer port interfaces, and operate under program control. The data modules being used are a combination of commercial and custom units, and include nanosecond time-interval digitizers, multi-channel 10-bit ADC's for fast pulse area measurements, and multiple pulse input time digitizers (time interval measurement) for use with a particular type of detector. An improvement program is now underway on this system to allow pre-processing of CAMAC information using micro-processors, and faster read-in using DMA. The modules and branch remain unchanged, however.

Figure 13 shows an example of a small, single user data acquisition system in which computer peripherals are interfaced directly to a PDP-11/40 computer on the DEC Unibus, while most data is acquired through commercially available CAMAC modules, connected by a standard parallel branch which is interfaced via a commercial micro-programmed branch driver. Essentially no hardware was custom-designed for this system. The user's main task for the data acquisition section was to develop a software driver for the CAMAC interface. This equipment was used by Xerox Research Division for an experiment at SLAC. A simpler, Type U crate controller was also used in this system for early runs.

Laboratory Control and Monitoring

Figure 14 shows a control and monitoring system for large DC power supplies for magnets in accelerator beamlines, which has many similarities to a typical industrial process control problem, namely, control and monitoring of heavy equipment over intermediate distances. The situation is complicated by the fact that a number of independent control points require access to different sub-systems over the same CAMAC branch. Also, reassignments of supplies to different control points (users) is sometimes required. This system at SLAC was built to replace a hardwired system with four main goals in mind:

1. To eliminate a large number of hardwired control/ monitoring cables by using the shared CAMAC branch
2. To reduce system reconfiguration problems by using software reassignment of supplies to each user, plus a possible relocation of a CRT terminal
3. To provide rapid setting and polarity reversing capability of systems of supplies, saving expensive experimental accelerator operating time; and significantly reducing energy consumption by rapid turn off/ on during idle periods and start up
4. To standardize power supply control hardware and interfaces, thus simplifying further expansion of the system, providing better centrally-located diagnostics capability, and simplifying field maintenance and training problems.

Most modules were custom-built, but standard peripherals such as the CRT terminals, TTY, etc. are interfaced directly via manufacturer's hardware and software. The external controllable devices, most of which are located in remote areas, are interfaced on a modified parallel branch.

Some problems of special concern were to achieve at least a 1 KV fault isolation protection at the control interface, and at least a 600 V isolation in the current shunt multiplexer modules. The typical power supply being controlled is constant current, 0.1% or better regulation, output dc voltages up to 600 V, and currents up to 10,000A. Because of the low-level shunt signals, a single, precise integrating DVM is used to successively monitor each signal through a separate multiplexed analog line. This normally would have been done over the CAMAC link with a precise integrating type ADC in each crate, except that the requirement of 600 V isolation made this unfeasible.

Figure 15 shows the central control and a CRT user station. All monitoring is provided by status displays on the CRT and all user control is implemented by a standard ASCII keyboard (not shown). All software is written in Fortran for maximum transportability, and is compiled on a larger host machine. ANSI standard Fortran was used, with simple driver subroutines added for the CAMAC.

The system is presently working with a single user control point, and expansion to two additional users is planned. The present branch in use for the initial phases is a parallel branch, but when the system is expanded it is planned to change to a serial system for cabling simplicity. Needless to say, the same modules will be used.

Computer Network System

Figure 16 shows an example of an application at Daresbury Laboratory in England where CAMAC has been used to interface standard peripherals as well as computer-computer links in a computer network.[8,9] This network consists of a central IBM370/165 processor, a variety of types of minicomputers supervising experimental data acquisition, a control computer for a large accelerator, and links to remote job entry work stations using interactive CRT terminals. High speed data links are implemented via CAMAC modules in remotely located crates. A long-range microwave link to a remote entry station has also been implemented. A set of macro instructions[10] has been standardized to facilitate implementation of interface software and to maximize transportability of high-level languages between different computers in the system. Peripherals which have been interfaced via this system include paper tape equipment, ROM modules, moving head discs, line printers, CRT terminals, high speed plotters, card and badge readers, and modem drivers.

This example demonstrates the use of CAMAC in a wide range of applications--interfacing of remote terminals to standard computing facilities, coupling of standard peripherals, coupling between computers in a network, and interconnection of systems for high-speed real time data acquisition and control, e.g., in all those areas where interfacing is an element in a large computer network.

9. Current and Future Activities of CAMAC Organizations

At the present time the standards organizations involved in CAMAC (NIM and ESONE) are pursuing new activities. One such activity is the preparation of guidelines for block transfers in CAMAC, in order to limit the number of different block transfer modes that are now possible, thereby simplifying controllers and interfaces, and aiding the module designer in selecting a mode of operation.

The software group in particular is currently working on two projects: (1) Fortran callable subroutines for CAMAC operation using IML related semantics (2) Extensions of BASIC to include CAMAC operations. These developments should provide software designers with guidelines for achieving new levels of compatibility in CAMAC system software.

Another activity of particular interest to IEEE is the study of the relation of the CAMAC standard to other existing digital standards--in particular, the "interface" between CAMAC and the recently published IEEE/488-1975 standard for programmable instruments[11]. One laboratory is already designing a CAMAC module to interface the IEEE 488 bus. The committee will carefully follow this development and cover other possible interrelations of these standards.

A new activity recently initiated is the result of impact of microprocessors on CAMAC; the committee has begun to consider the possibilities of distributed control within the CAMAC system. As previously discussed, microprocessors are already usable within CAMAC, and in fact, microprocessor crate controllers exist. However, the new activity is aimed at <u>fully</u> realizing the potential of distributed control (multiple sources of control) within the CAMAC structure. Needless to say, any changes that are made in the standard will be additional features, and older modules will not become obsolete.

The CAMAC Industry Applications Group (CIAG) is studying applications of CAMAC to process control. Items of interest are the additional packaging appropriate for that environment, appropriate techniques of grounding and shielding, and cable termination.

10. Sources of CAMAC Information

Of course the basic CAMAC specification IEEE-583 is available through the usual channels of the IEEE. The other CAMAC documents discussed in this article are available from the U. S. Government Printing Office, Washington, D. C., as listed in the references at the end of this report. For further information on these documents and technical questions on CAMAC committee activities, contact Mr. Louis Costrell, National Bureau of Standards, Washington, D. C. 20234.

A publication is devoted to CAMAC activities and technical developments. The "CAMAC Bulletin", published three times a year in Europe, also periodically contains very complete indices of all commercial CAMAC products, listed by function. Information on subscriptions is available from Commission Des Communautes Europeennes, D. G. VIII 29 rue Aldringen, Luxembourg.

Many articles have been published on applications and developments of CAMAC in technical journals, including the IEEE Transactions on Nuclear Science[12, 13], and in other journals as well[14, 15]. Several tutorial articles have been written[16]. Recent survey articles describe the present status of CAMAC in North America[17, 18].

In addition, the IEEE periodically runs full day tutorial sessions on the CAMAC standards in various selected locations in the United States.

For those users interested in the activities of the CAMAC Industry Applications Group, contact Mr. Dale Zobrist, ALCOA Building, Pittsburgh, Pennsylvania 15219.

LIST OF REFERENCES

1. IEEE STD-583-1975: Standard Modular Instrumentation and Digital Interface System (CAMAC)

2. AEC Report TID-25875: CAMAC, A Modular Instrumentation System for Data Handling, 1972 (Rev)

3. AEC Report TID-25877: Supplementary Information on CAMAC Instrumentation System, 1972

4. AEC Report TID-25876: CAMAC, Organization of Multi-Crate System, 1972

5. AEC Report TID-26488: CAMAC, Serial System Organization, A Description, 1973

6. AEC Report TID-26615: CAMAC, The Definition of IML, A Language for Use in CAMAC Systems, 1975

7. AEC Report TID-26614: CAMAC, Specification of Amplitude Analog Signals Within a 50 Ω System

8. B. Zacharov, SRC, Daresbury Laboratory, England, CAMAC Bulletin No. 9, April 1974: "CAMAC As a Processor Interface in Computer Networks"

9. A. C. Peatfield et al, SRC, Daresbury Laboratory, England, CAMAC Bulletin No. 9, April 1974: "CAMAC As a Computer Peripheral Interface System"

10. CAMACRO, An Aid to CAMAC Interface Programming, CAMAC Bulletin No. 5, November 1972

11. IEEE STD-488-1975: IEEE Standard Digital Interface for Programmable Instrumentation

12. IEEE Trans. on Nuclear Science NS-21, No. 1, Feb. 1974, Proceedings of 1973 Nuclear Science Symposium

13. IEEE Trans on Nuclear Science, NS-23, No. 1, Feb. 1975, Proceedings of 1974 Nuclear Science Symposium

14. R. A. Gore and D. R. Machen, Proc. of the IEEE, V61, No. 11, Nov. 1973, pp. 1589-1596: "The Use of Minicomputers in Particle Accelerators"

15. D. L. Abbot, COMPCON, 74, Proceedings, San Francisco, CA, p. 307, "Microprocessors and CAMAC - Modular Peripheral Interfaces with Distributed Intelligence"

16. IEEE Trans. on Nuclear Science, NS-20, No. 2, April 1973, CAMAC Tutorial Issue

17. D. Mack and L. Wagner, "Application and Development of CAMAC in North America in 1975", LBL-3819, May 9, 1975

18. D. Horelick and R. S. Larsen, "Status of CAMAC in North America, 1975", SLAC-PUB-1642,September 1975

APPENDIX A

FUNDAMENTALS OF IEEE 583 - THE CAMAC CRATE AND MODULES

The concept of the crate-module pair is fundamental to the CAMAC standard. The crate itself is a housing for the modules and the home of the Dataway, or motherboard. The Dataway is simply an interconnection method for the modules and the crate controller. All signals on the Dataway are digital, with standard TTL levels. As shown in Figure A-1 the Dataway is composed of bussed connections <u>except</u> for the station lines N, and Look-At-Me (LAM, or service request) lines which are individual point-to-point connections between each of the module stations and the crate controller. The N line, when active or "1" indicates to the respective module that the command on the command bus pertains to that module. Likewise the L line when active indicates to the crate controller that the respective module requires service. Note that the use of individual lines for N and L permits simultaneous actions in many modules.

Multiplexing from the modules is accomplished by open collector gates. That is, all signals transferring from the module <u>to</u> the Dataway are transferred via open collector gates such as the SN7401; in turn the entire crate acts as an intrinsic multiplexer when these gates in the modules are controlled by the respective N lines. For data transfer from the Dataway to the module the crate acts as a "distributor". In this case the N lines control which module or modules accept the data.

The basic crate controller-module interface is shown in Figure A-2. The command lines include 5 function code and 4 subaddress lines. The 5 function code lines are coded into 32 function codes, of which about half are defined to achieve a degree of operational compatibility between modules. For example, F(0) is defined as "Read data from a module"; F(16) is "Write data to a module". The 4 subaddress lines are used to subdivide the module into 16 entities, referred to as "registers", but in a broader sense they are simply "subdivisions". For example, F(0), A(0) reads data from one register, whereas F(0), A(1) reads data from another register in that module. The subaddress entities need not be parallel arrays. For example, F(25), A(0) means "Execute" (which might mean send out a pulse) on channel 0; F(25), A(1) means execute on channel 1 (send out a pulse on channel 1).

Commands are addressed; that is, they are performed only in those modules where the N line indicates to do so. There are also unaddressed commands, sent as single line commands, which apply to all modules; these in particular are Initialize (Z), Clear (C), Inhibit (I), Busy (B). The first three are of obvious meaning, the last signifies that a Dataway cycle is in progress or an unaddressed command is being sent.

A Dataway cycle includes two timing signals, S1 and S2, usually generated by the crate controller. S1 is used as a strobe to accept data from the Dataway; S2 is used for initiating actions that may change the state of the Dataway Read or Write lines. Thus it is apparent that the CAMAC cycle is a synchronous two phase timing sequence where data is read or loaded (transferred) on S1, and changed (cleared or sequenced) on S2. There is no standard cycle time, but a minimum of 1 μsec is specified, and all modules must meet this specification to achieve full interchangeability of modules in systems.

All data is transferred within a crate in parallel format. There are 24 Read lines and 24 Write lines; thus up to 24 bit parallel transfers are handled. Although there is no specification on a "preferred" word size or type of coding, it is suggested that crate controllers handle the full 24 bits so that all possible modules can be serviced. Binary data coding has of course been predominant. Note that the word "Data" is used loosely here--the terms "Read" and "Write" only imply direction of transfer and the data may actually be control information. For example, F(16), Write Group 1 Register, may be used to send 24 bits of individual on-off information to a register in a module, from which the signals are sent to the process under control.

Two response bits are specified which return from a module via two busses. The first, X, is defined as "Command Accepted". This is simply an affirmation that a module is present in the designated station, and is equipped to do the action required; that is, the particular function code and subaddress are present. The Q response bit is not so rigidly defined, and in fact is a generalized response signal to be used as the designer sees fit. In addition, certain function codes used to test features of the module use the Q bit to send the yes-no reply. Another use of the Q bit is a control bit for block transfers. Three types of block transfers using Q are defined at the present time.

As mentioned previously, the L line is the source of an interrupt request from a module. The use of individual L lines allows immediate identification of a request. However, in the general case many different interrupt requests may be generated within a module, all OR'ed onto the single L line. The standard provides guidelines for the control and rapid identification of these multiple interrupts. Although several methods are suggested, probably the most powerful is to treat the interrupts in a parallel fashion and then read and control interrupt registers using the read and write lines as parallel data. For example, using F(1) A(14) reads interrupt requests directly using the Read lines; using F(17) A(13) writes into an interrupt mask register in the module. These operations permit up to 24 interrupts in a module--more than sufficient for most applications.

Along with all of these digital signals for conveying information, the Dataway also provides the power for the modules. The standard voltages are +6V, -6V, +24V, and -24V. Additional pins have been assigned for +12V, -12V, 117 Vac, and +200V, but these are considered special voltages.

APPENDIX B

Typical Examples

The following simple examples illustrate the basics of module design. The first example (Figure B-1) shows the logic in a module associated with reading of up to 24 bits of data using F(0), A(0). A nine input gate recognizes the N line and the proper command, and enables the 7401 output gates onto the Dataway Read lines. In addition, response X=1 is returned, Q=1 is also returned to permit reading the module in a block transfer if desired. Note that neither S1 nor S2 is used in this example.

The second example (Figure B-2) shows an example of Write logic using F(16) A(0). In this case the data on the Write lines is loaded into a flip-flop register in the module. Since data is being accepted from the Dataway, the S1 pulse is used for clocking the register. Once again X and Q are returned as "1's" for the same reasons as before. Note also the use of Z as an unaddressed command to clear the register; gating with S2 is specifically required to guard against inadvertent clearing.

Figure B-3 illustrates the principles of implementing an interrupt subsystem within a module, treating the interrupts as parallel registers.

PARTIAL LIST OF U. S. MANUFACTURERS

1. Bi-Ra Systems Inc.
   3520 D Pan American Freeway, N.E.
   Albuquerque, New Mexico 87107

2. Digital Equipment Corp.
   146 Main Street
   Maynard, Massachusetts 01754

3. EGG/ORTEC
   500 Midland Rd.
   Oak Ridge, Tennessee 37830

4. Joerger Enterprises
   32 New York Ave.
   Westbury,New York 11590

5. Jorway Corp.
   27 Bond St.
   Westbury, New York 11590

6. Kinetic Systems Corp.
   Maryknoll Dr.
   Lockport, Illinois 60441

7. LeCroy Research Systems Corp.
   126 North Route 303
   West Nyack, New York 10994

8. Nuclear Enterprises
   935 Terminal Way
   San Carlos, California 94070

9. Nuclear Specialties
   6341 Scarleti Court
   Dublin, California 94566

10. Standard Engineering Corp.
    44800 Industrial Dr.
    Fremont, California 94538

LIST OF FIGURE CAPTIONS FOR SPECTRUM

FIGURE	CAPTION
1.	Independent Standardized Bus Structure Permits Computer-Independent Interfaces
2.	Typical Powered CAMAC Crate and Module A fully powered crate costs about $1500, an unpowered crate about $700.
3.	The Basic Dataway Interface to a Module All signals are TTL levels, and the power voltages are ± 6 V, ± 24 V.
4.	Connection to a Crate is Made Via a Crate Controller (CC)
5.	A Commercial Microprocessor Crate Controller Based on the Intel 8080 (Photo courtesy Standard Eng. Corp.)
6.	The Concept of the Parallel Branch, which Controls up to 7 Crates
7.	A Commercial Type A-1 Crate Controller For the Parallel Branch. These cost about $800. (Photo courtesy Standard Eng. Corp.)
8.	The Concept of the Serial System Communication between crates may be via any serial bit communication scheme. Byte serial, using 8 data lines plus clock is also possible for higher speed.
9.	A Commercial SCC-L1 These cost about $1700, and run up to 5 MHz clock rate. (Photo courtesy Kinetic Systems Corp.)
10.	A Commercial Module for Synchro to Digital Conversion This one converts the angle to a 10 bit number, and includes a 12 bit turns counter. (Photo courtesy ALCOA)
11.	This Commercial Module Provides an Interface for Process Transducers that Generate Variable Width Telemetry Signals (Photo courtesy ALCOA)
12.	Block Diagram of a Large Multi-User Data Acquisition System All experimental data from detectors is entered via CAMAC modules.
13.	Block Diagram of a Small Single User System for an Experiment All equipment is commercially available.
14.	A System for Computer Control and Monitoring of DC Magnets Full photon-coupled isolation was provided between the magnets and the CAMAC crates.
15.	Central Control and User Control Station for the Magnet Control System in Fig. 14 The Nova 1220 computer and a local CAMAC crate are visible in the background. The branch driver is directly above the computer.

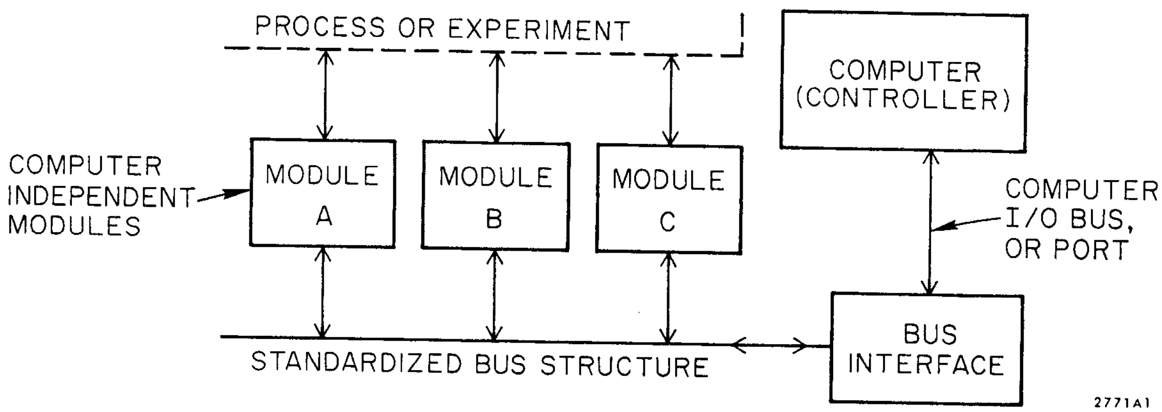
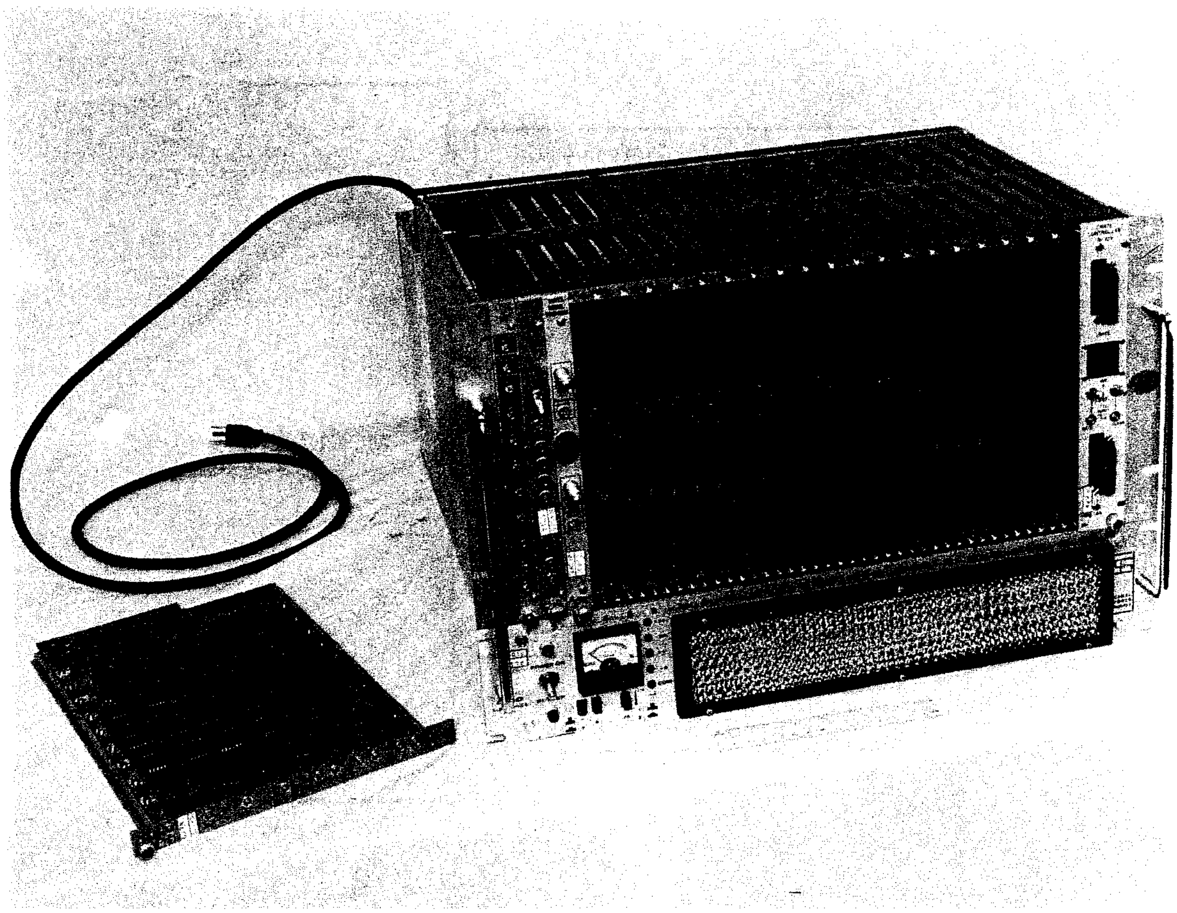

PROCESS OR EXPERIMENT
COMPUTER (CONTROLLER)
COMPUTER INDEPENDENT MODULES
MODULE A
MODULE B
MODULE C
COMPUTER I/O BUS, OR PORT
STANDARDIZED BUS STRUCTURE
BUS INTERFACE
2771A1

FIG. 1



2771A15

FIG. 2

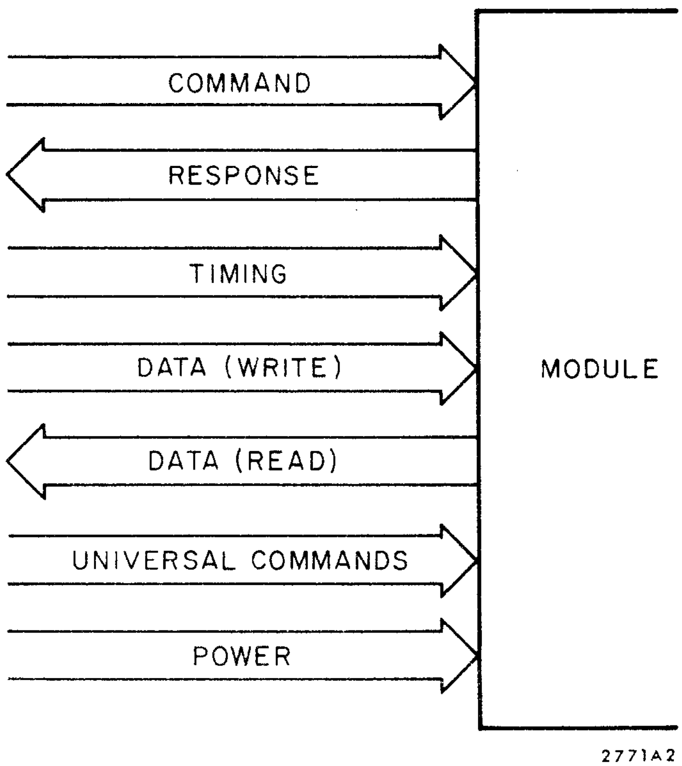

COMMAND
RESPONSE
TIMING
DATA (WRITE)
DATA (READ)
UNIVERSAL COMMANDS
POWER
MODULE
2771A2

FIG. 3

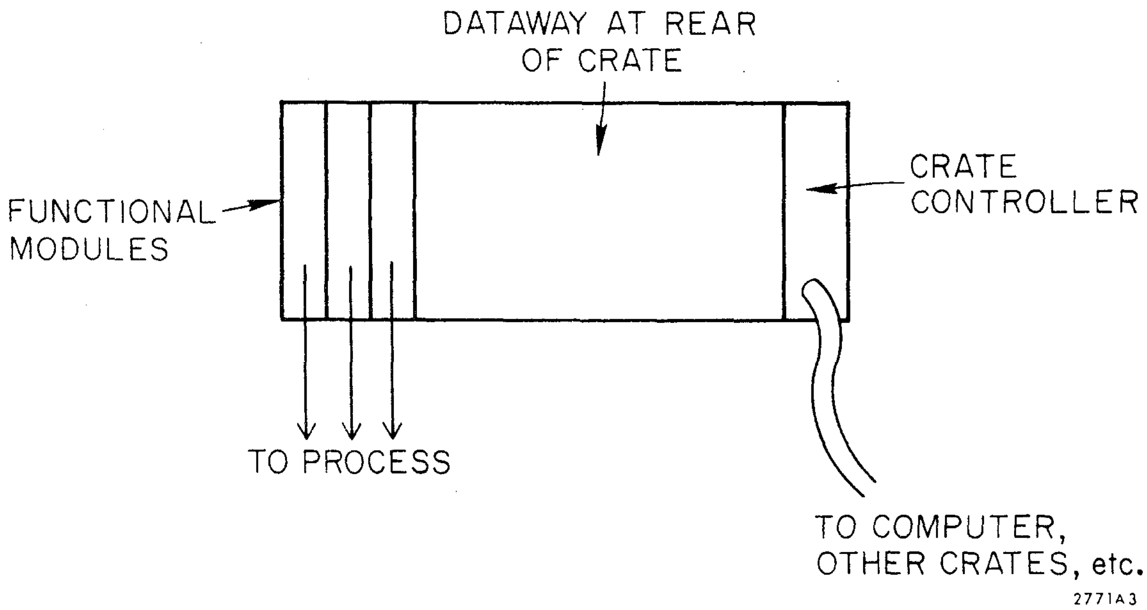
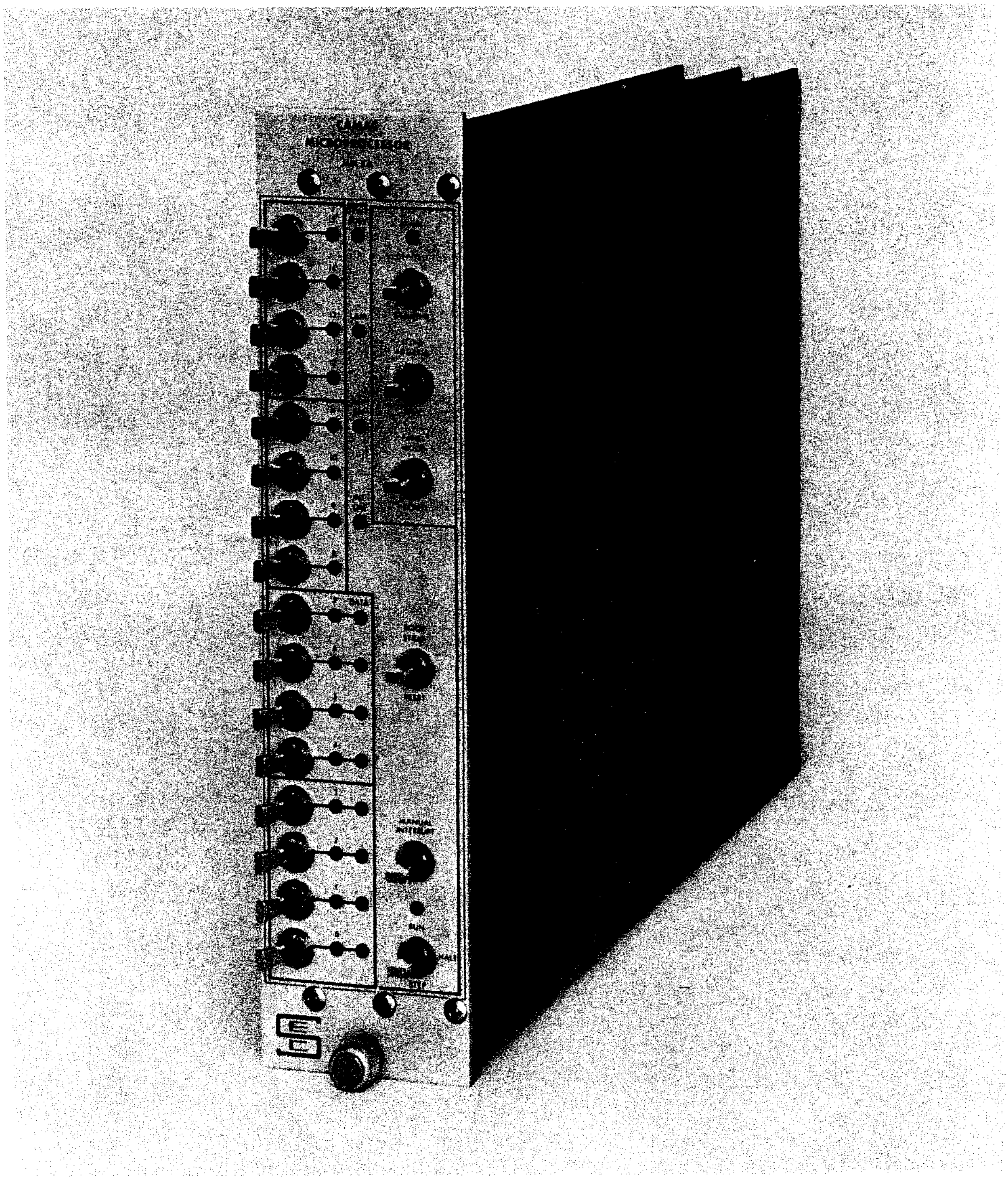

DATAWAY AT REAR
OF CRATE
CRATE
CONTROLLER
FUNCTIONAL
MODULES
TO PROCESS
TO COMPUTER,
OTHER CRATES, etc.
2771A3

FIG. 4



2786A6

FIG. 5

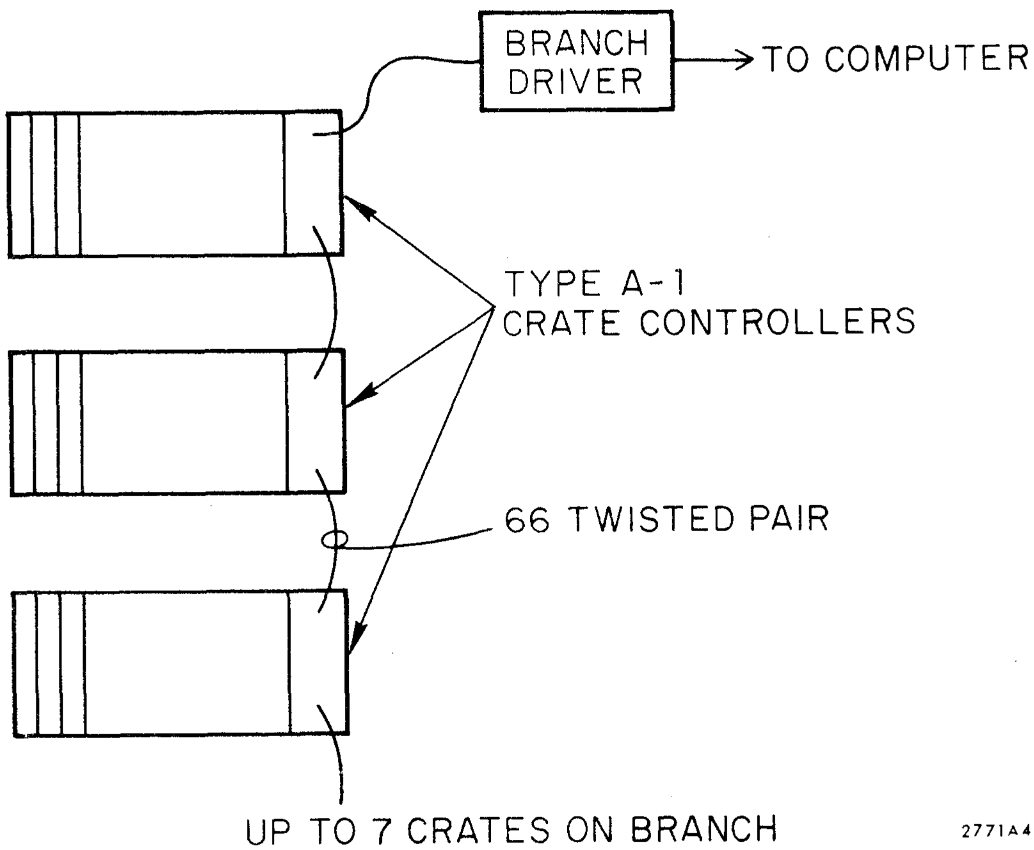
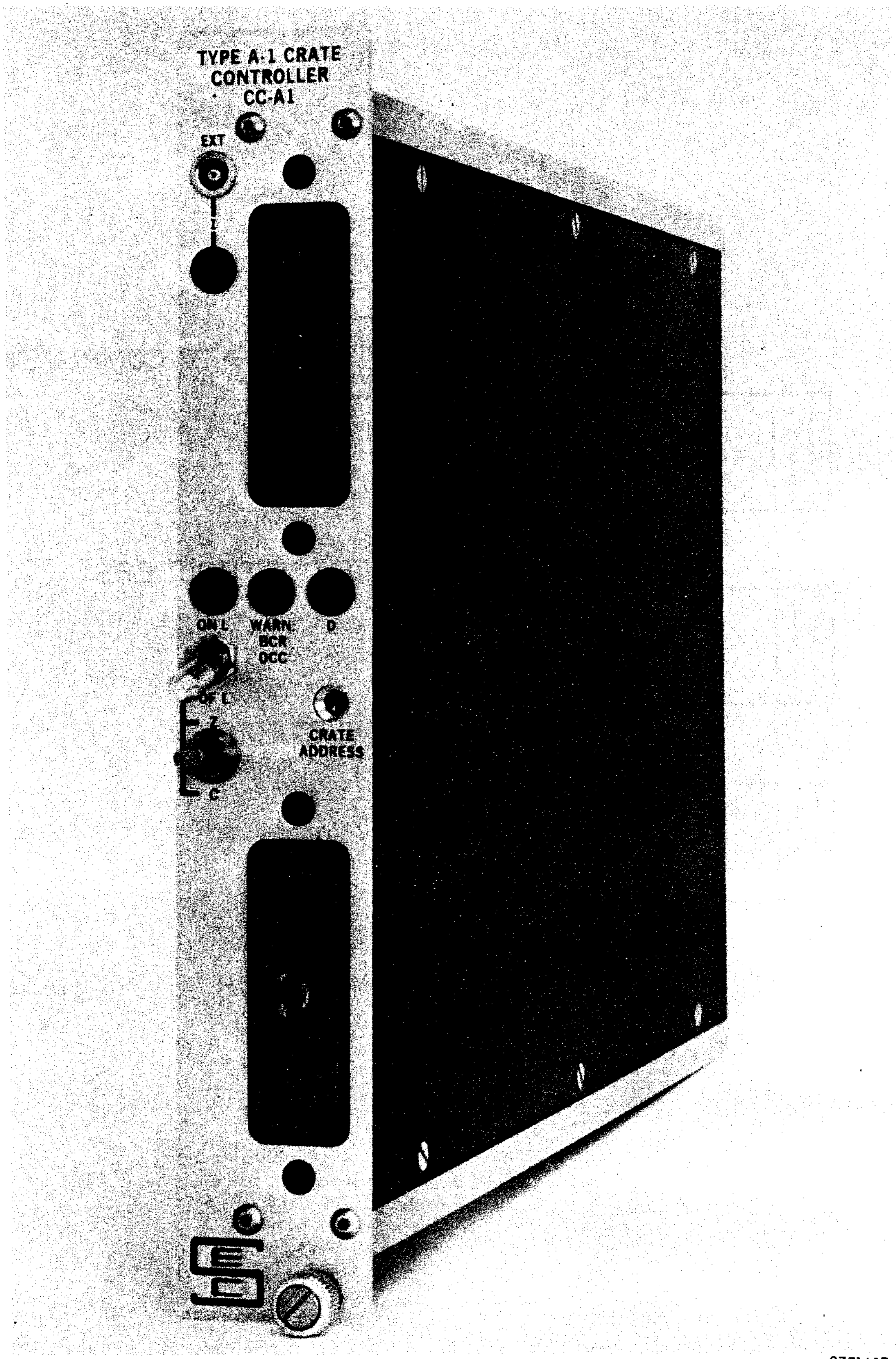

BRANCH
DRIVER
TO COMPUTER
TYPE A-1
CRATE CONTROLLERS
66 TWISTED PAIR
UP TO 7 CRATES ON BRANCH
2771A4

FIG. 6



2771A17

FIG. 7

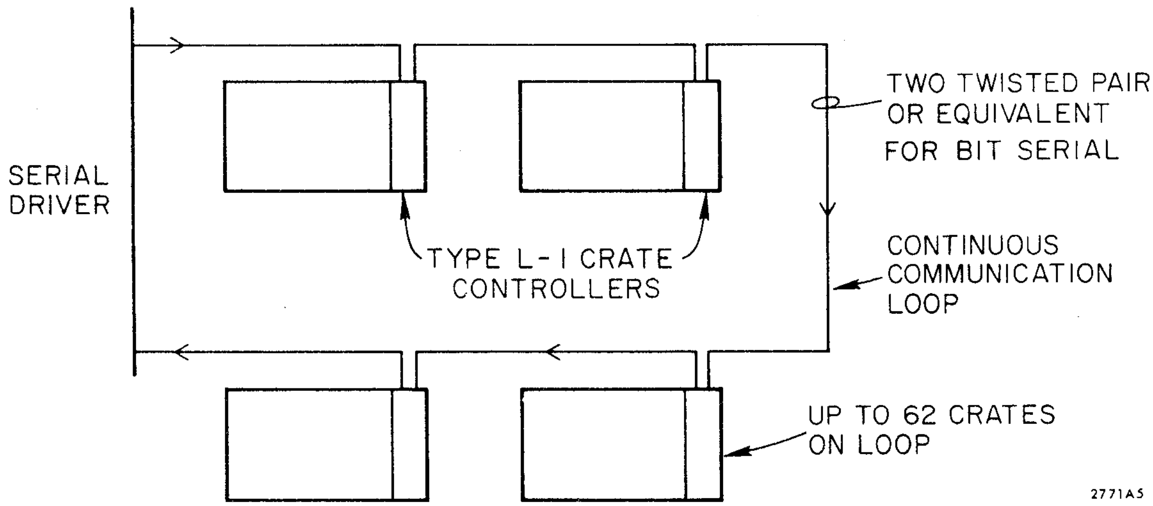
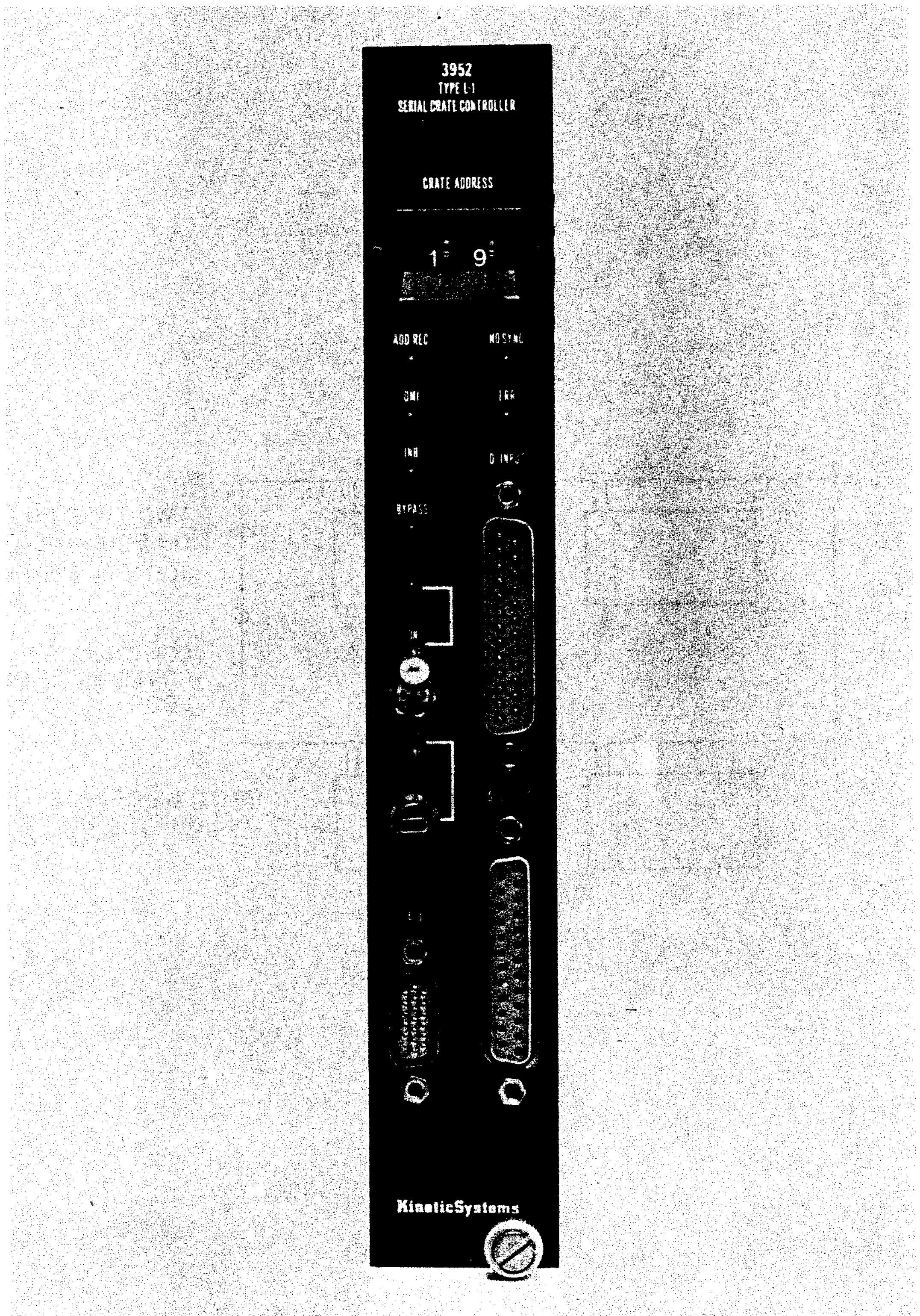

TWO TWISTED PAIR
OR EQUIVALENT
FOR BIT SERIAL
SERIAL
DRIVER
TYPE L-1 CRATE
CONTROLLERS
CONTINUOUS
COMMUNICATION
LOOP
UP TO 62 CRATES
ON LOOP
2771A5

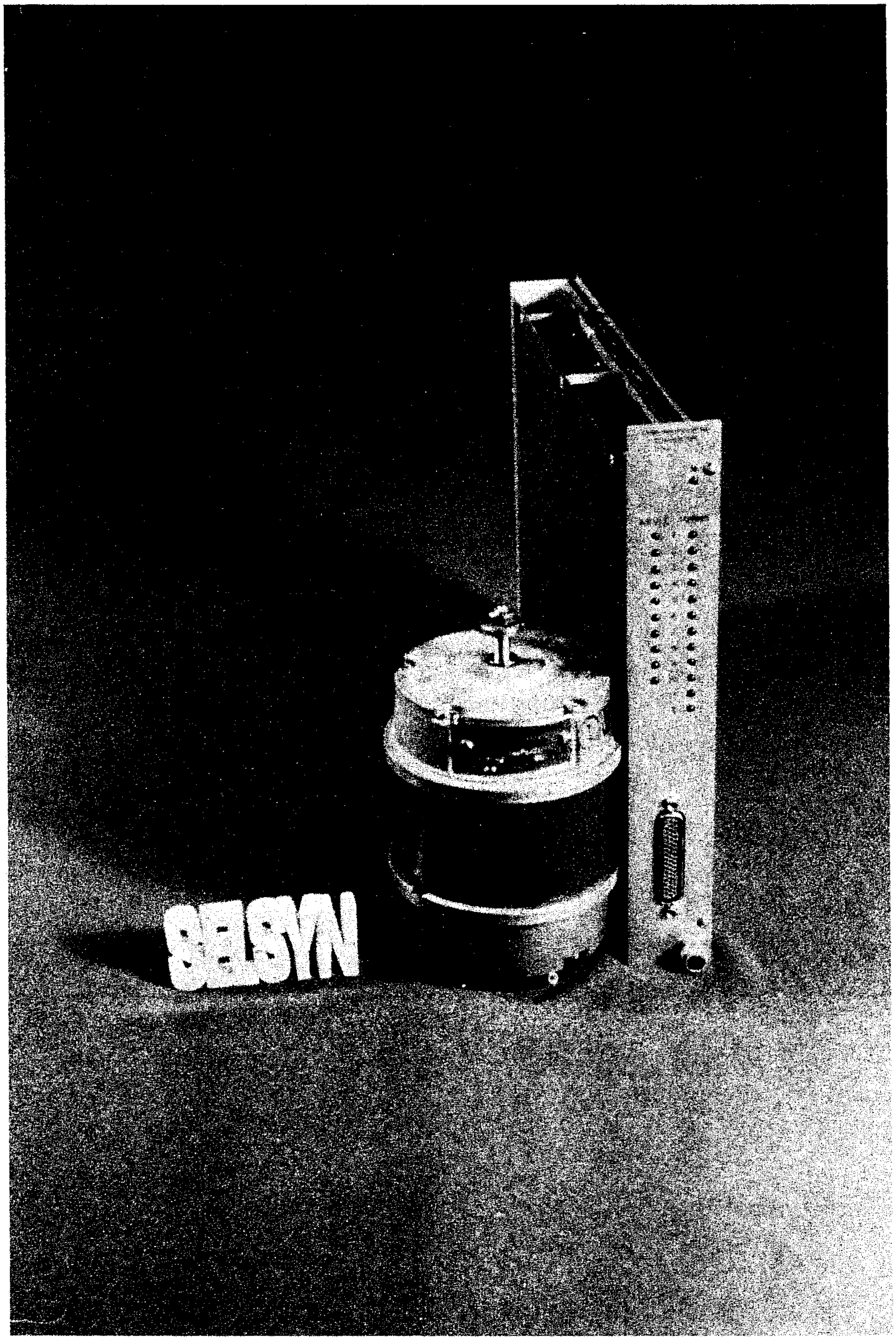
FIG. 8



3952
TYPE L-1
SERIAL CRATE CONTROLLER
CRATE ADDRESS
ADD REC
NO SYNC
ERR
INH
BYPASS
KineticSystems

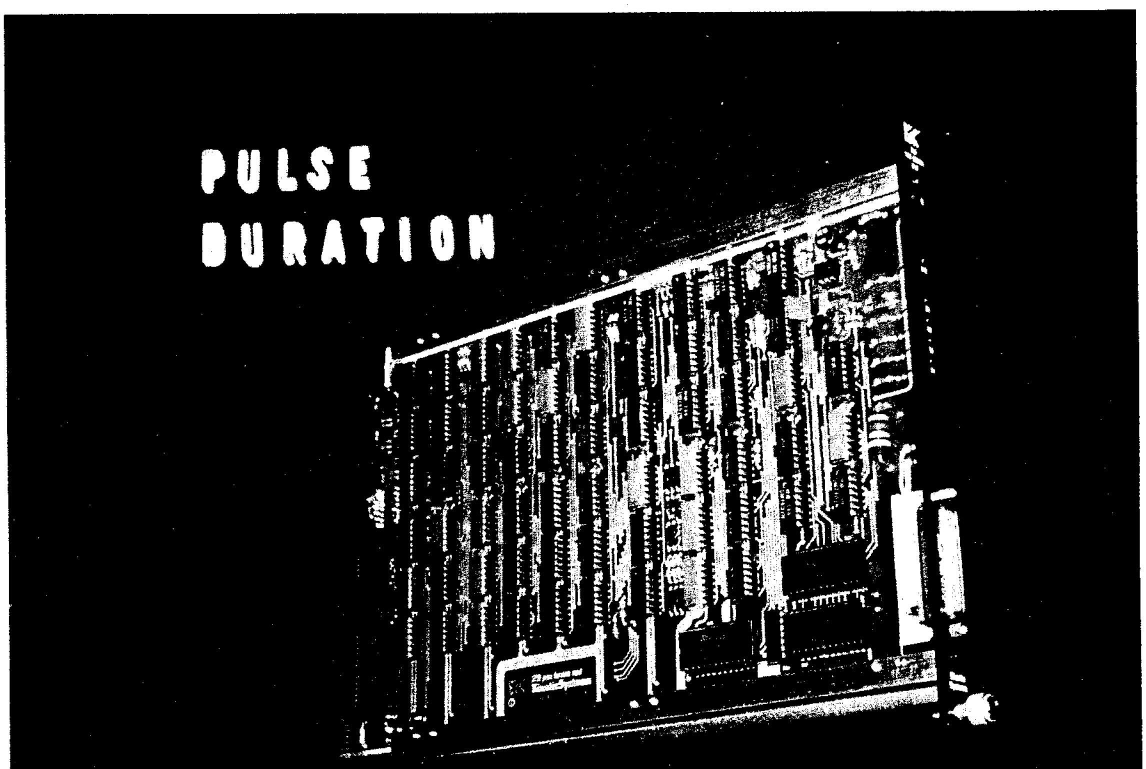
2786A5

FIG. 9



2771A18

FIG. 10



2771A19

FIG. 11

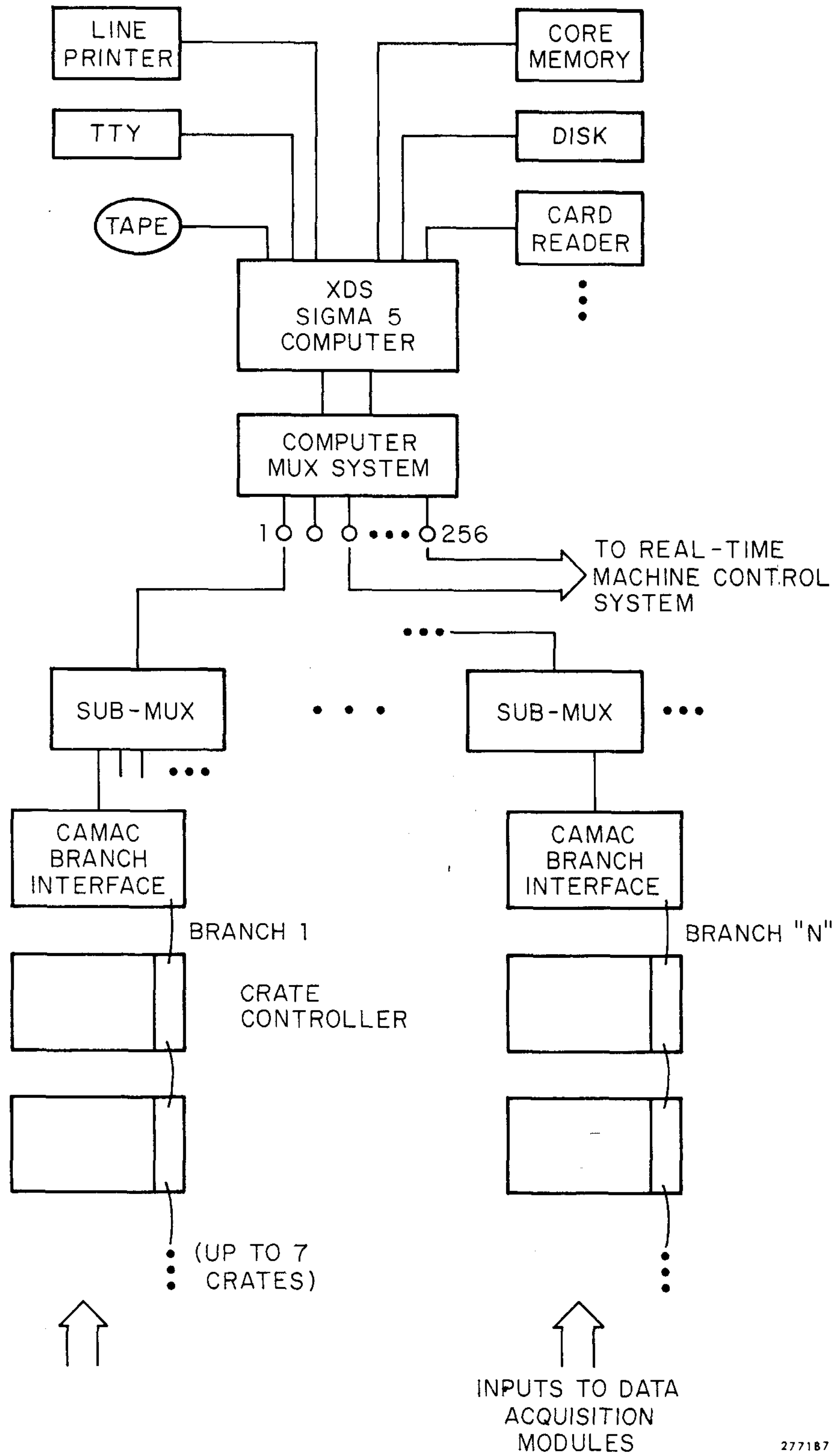

LINE PRINTER
TTY
TAPE
CORE MEMORY
DISK
CARD READER
XDS SIGMA 5 COMPUTER
COMPUTER MUX SYSTEM
1
256
TO REAL-TIME MACHINE CONTROL SYSTEM
SUB-MUX
SUB-MUX
CAMAC BRANCH INTERFACE
CAMAC BRANCH INTERFACE
BRANCH 1
BRANCH "N"
CRATE CONTROLLER
(UP TO 7 CRATES)
INPUTS TO DATA ACQUISITION MODULES
277187

FIG. 12

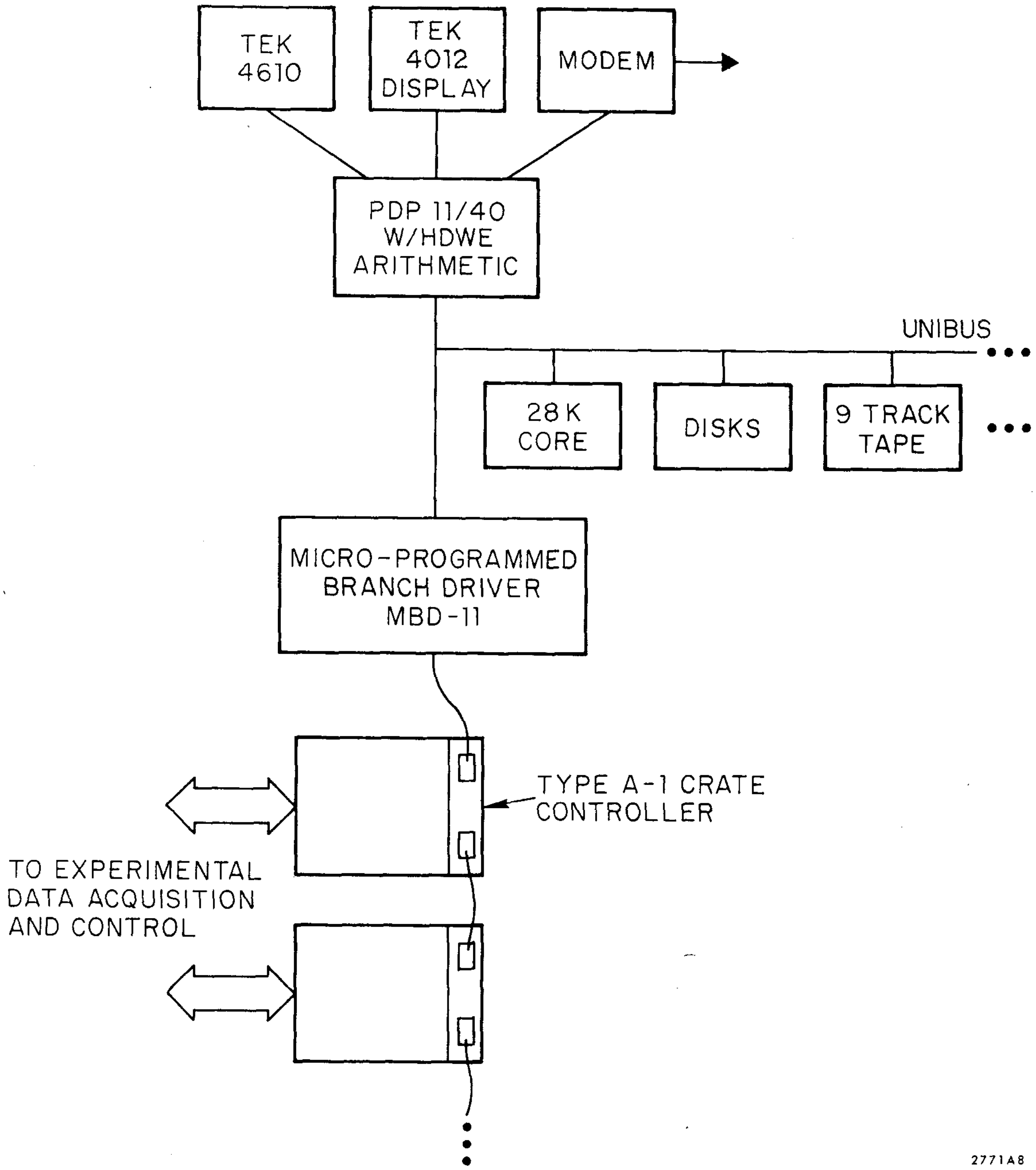

TEK
4610
TEK
4012
DISPLAY
MODEM
PDP 11/40
W/HDWE
ARITHMETIC
UNIBUS
28 K
CORE
DISKS
9 TRACK
TAPE
MICRO-PROGRAMMED
BRANCH DRIVER
MBD-11
TYPE A-1 CRATE
CONTROLLER
TO EXPERIMENTAL
DATA ACQUISITION
AND CONTROL
2771A8

FIG. 13

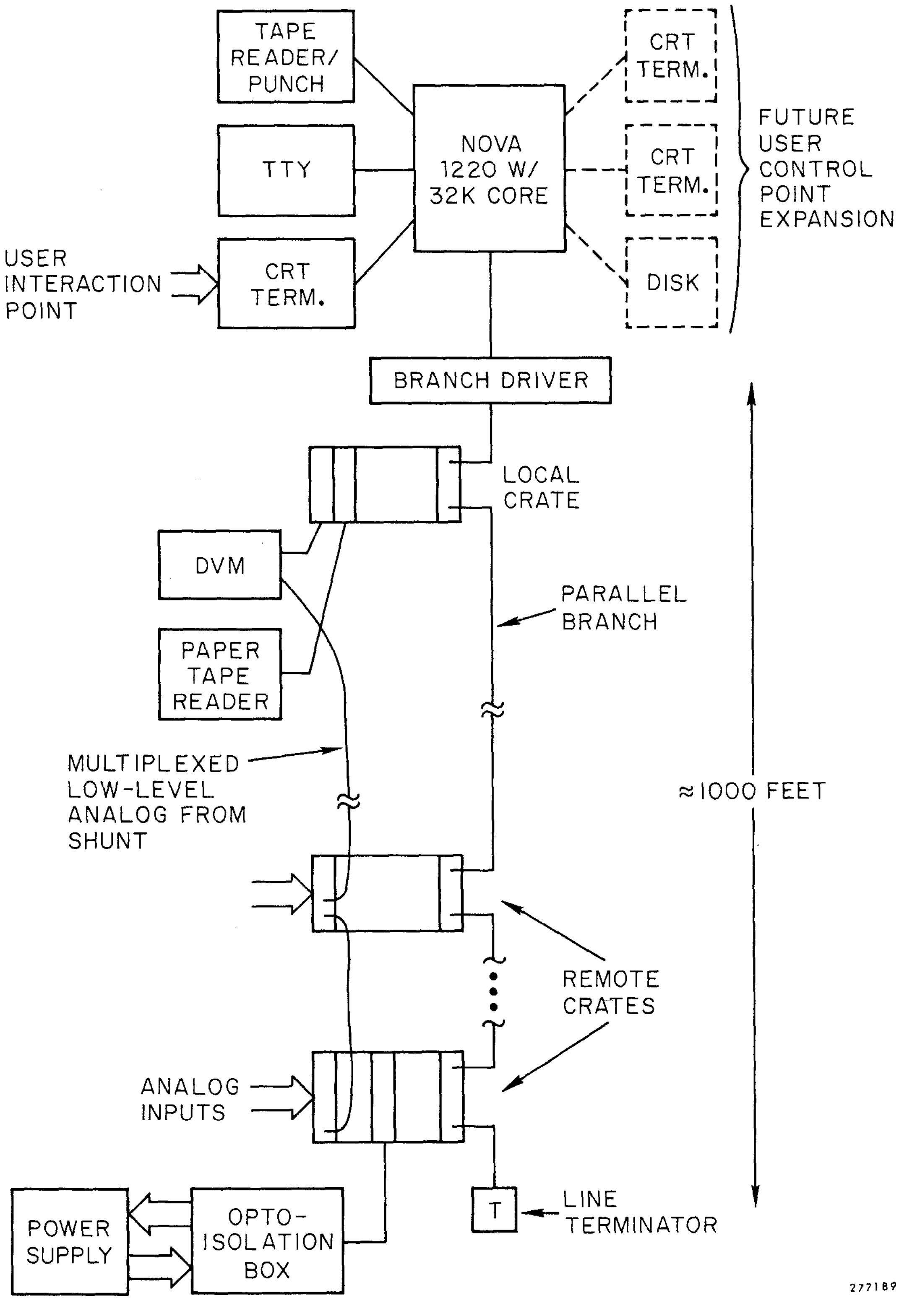
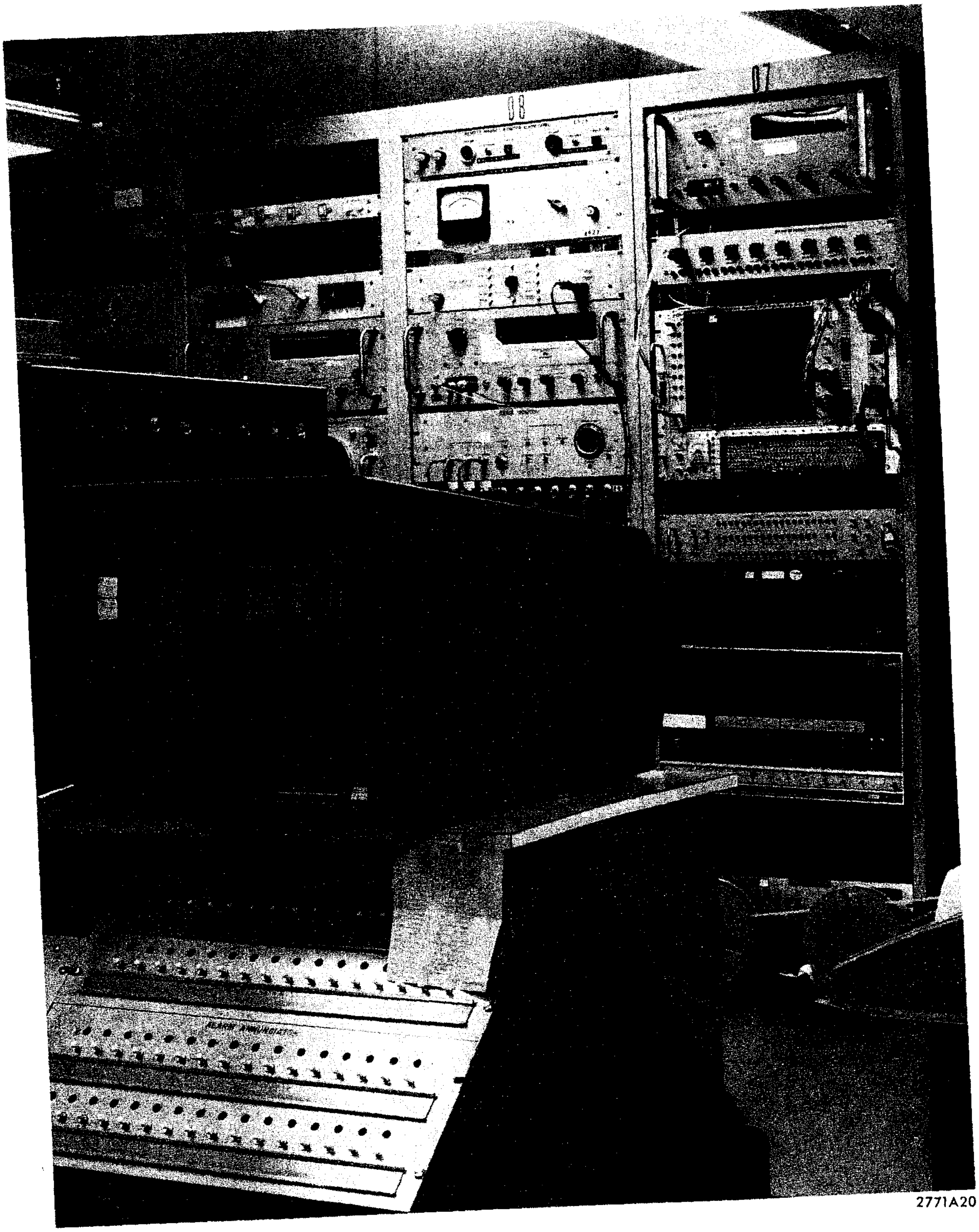

TAPE READER/ PUNCH
TTY
USER INTERACTION POINT
CRT TERM.
NOVA 1220 W/ 32K CORE
CRT TERM.
CRT TERM.
DISK
FUTURE USER CONTROL POINT EXPANSION
BRANCH DRIVER
LOCAL CRATE
DVM
PAPER TAPE READER
PARALLEL BRANCH
MULTIPLEXED LOW-LEVEL ANALOG FROM SHUNT
≈1000 FEET
REMOTE CRATES
ANALOG INPUTS
POWER SUPPLY
OPTO-ISOLATION BOX
T
LINE TERMINATOR
277189

FIG. 14



2771A20

FIG. 15

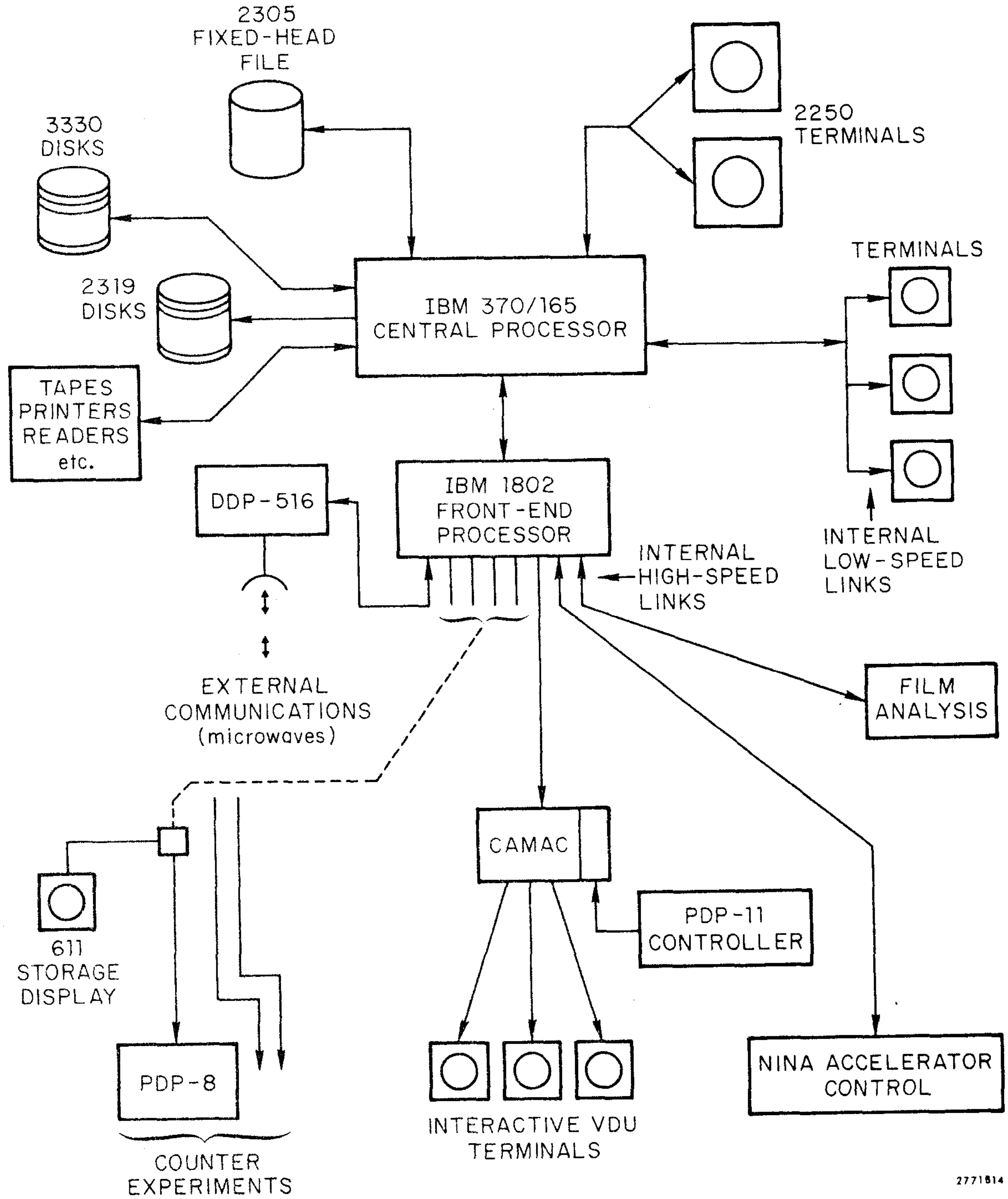

2305
FIXED-HEAD
FILE
3330
DISKS
2250
TERMINALS
TERMINALS
2319
DISKS
IBM 370/165
CENTRAL PROCESSOR
TAPES
PRINTERS
READERS
etc.
DDP-516
IBM 1802
FRONT-END
PROCESSOR
INTERNAL
HIGH-SPEED
LINKS
INTERNAL
LOW-SPEED
LINKS
EXTERNAL
COMMUNICATIONS
(microwaves)
FILM
ANALYSIS
CAMAC
PDP-11
CONTROLLER
611
STORAGE
DISPLAY
PDP-8
NINA ACCELERATOR
CONTROL
INTERACTIVE VDU
TERMINALS
COUNTER
EXPERIMENTS
2771B14

FIG. 16

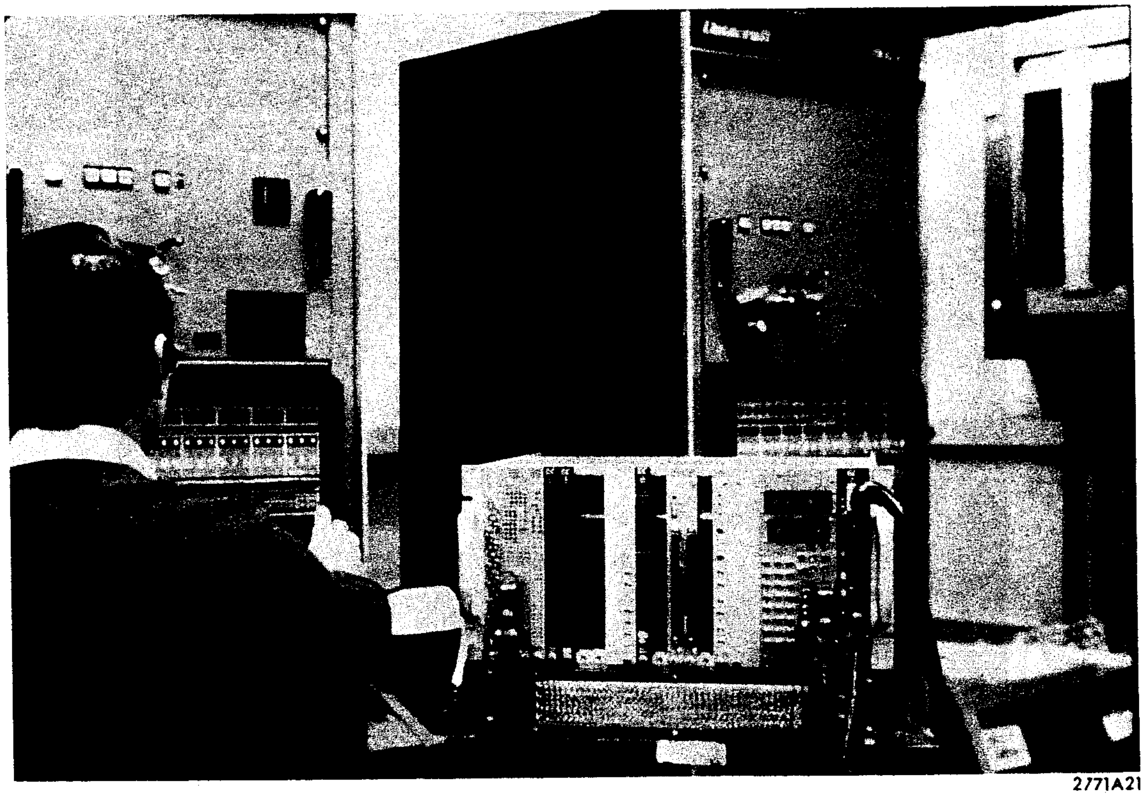
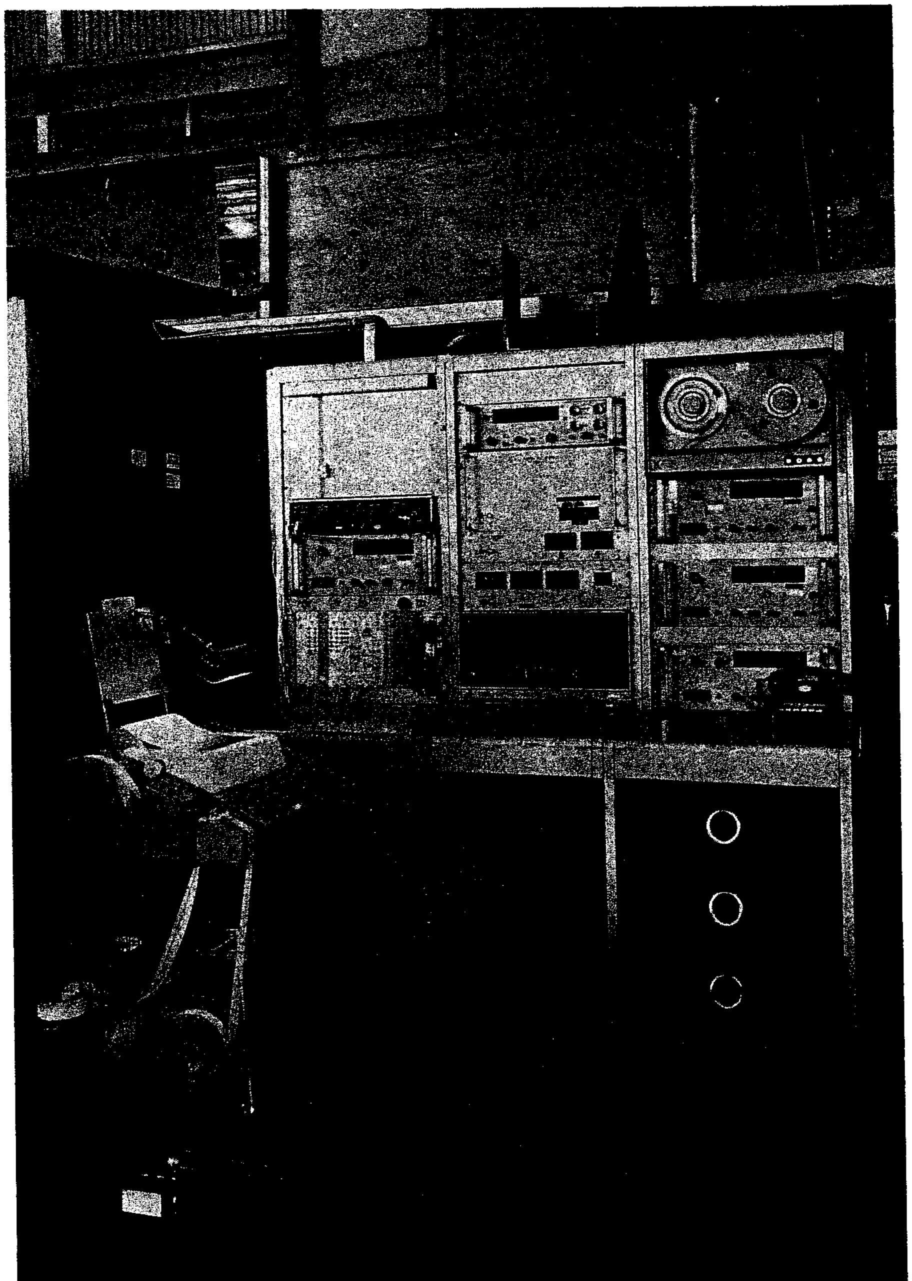

2771A21

FIG. 17



2786A7

FIG. 18

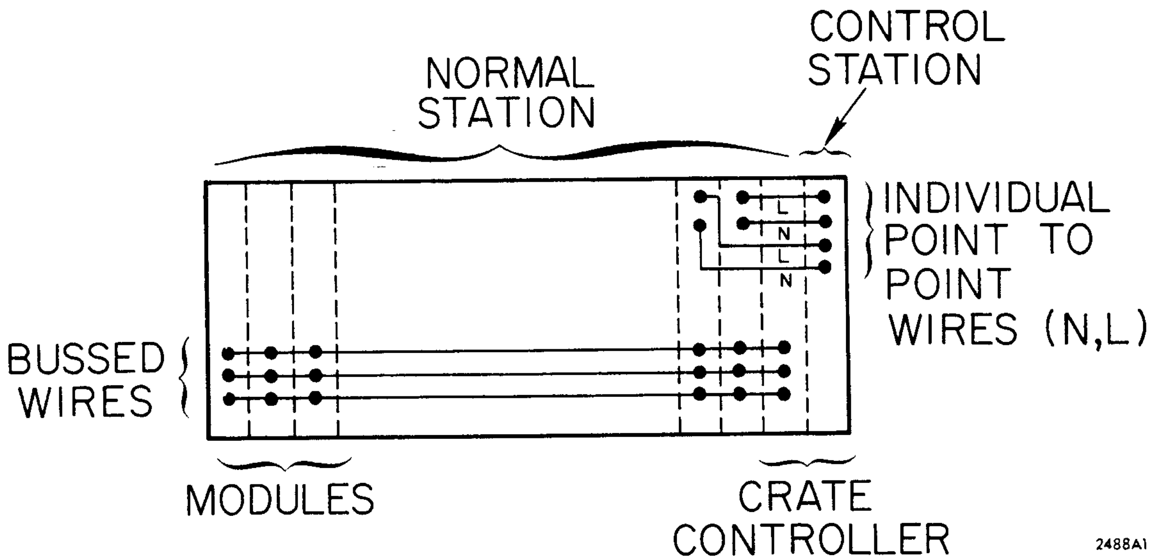

CONTROL
STATION
NORMAL
STATION
INDIVIDUAL
POINT TO
POINT
WIRES (N,L)
L
N
L
N
BUSSED
WIRES
MODULES
CRATE
CONTROLLER
2488A1

FIG. A-1

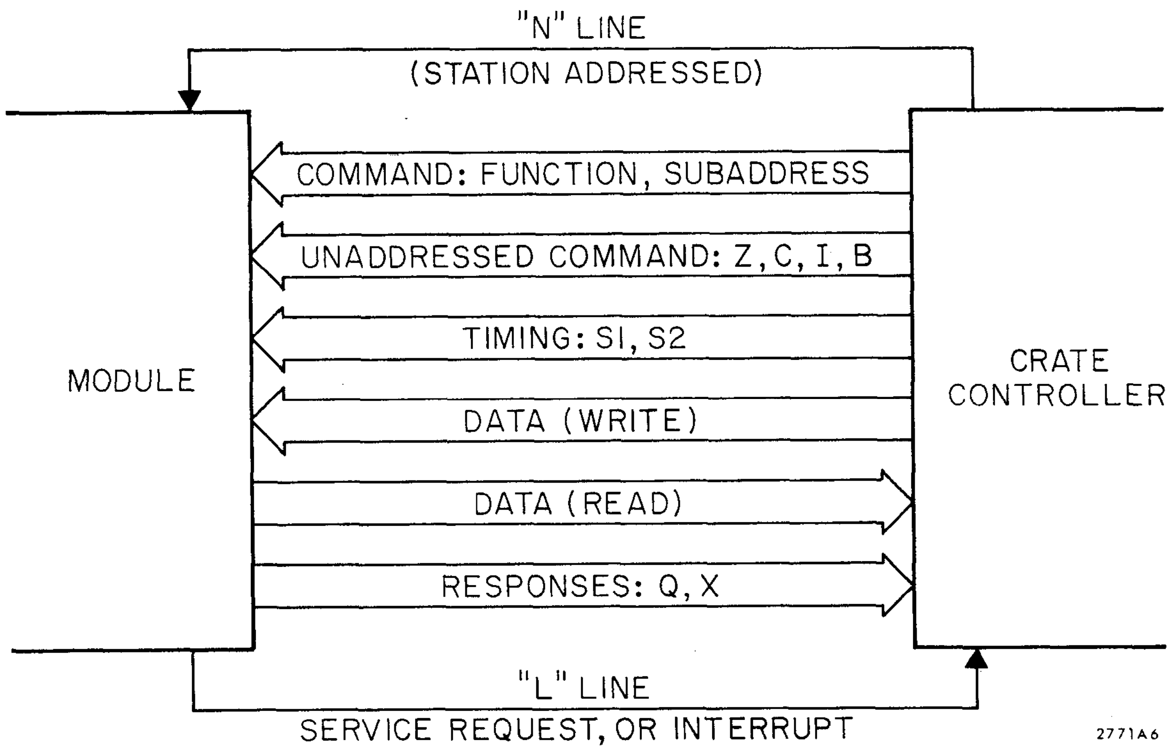
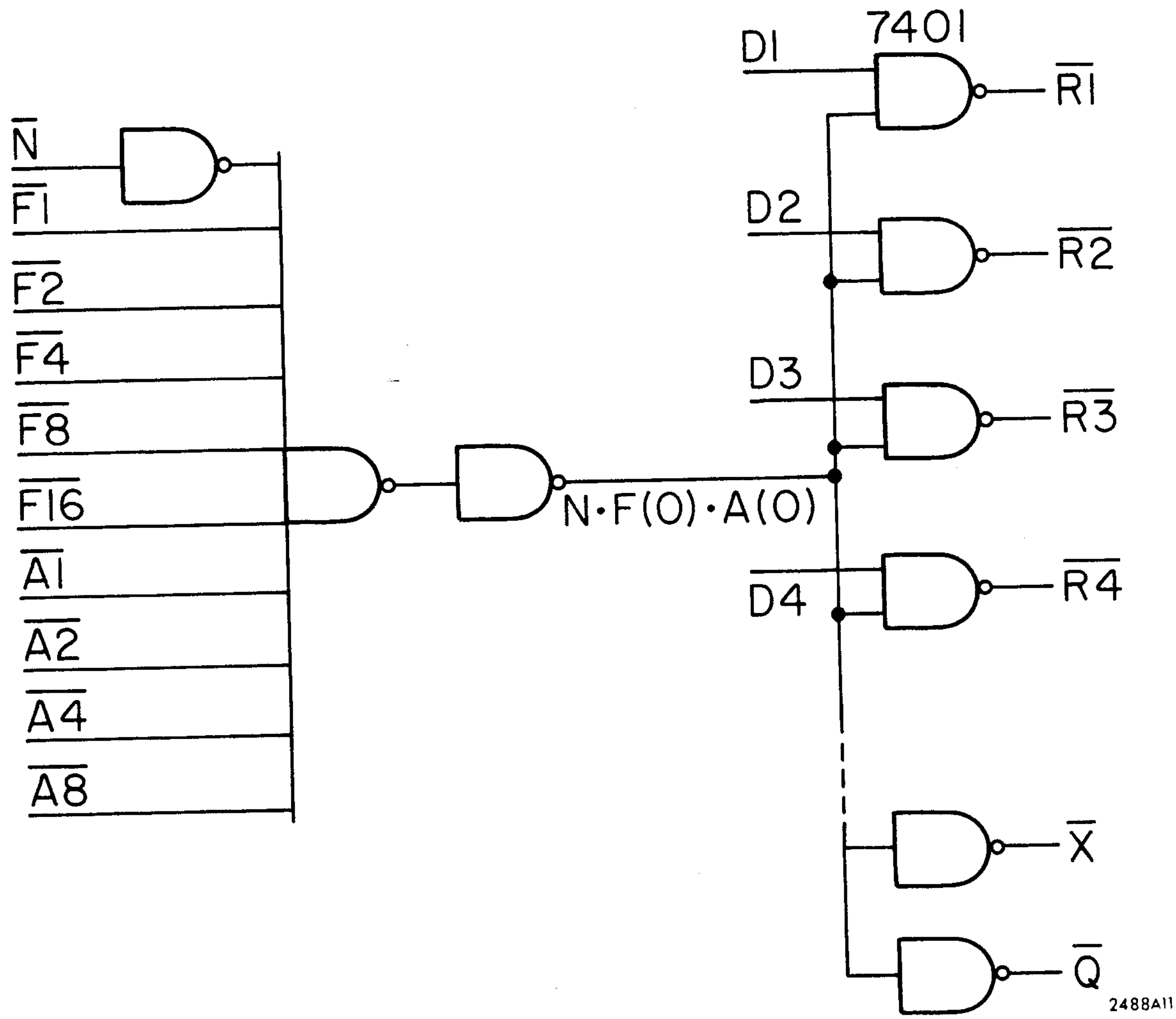

"N" LINE
(STATION ADDRESSED)
COMMAND: FUNCTION, SUBADDRESS
UNADDRESSED COMMAND: Z, C, I, B
TIMING: S1, S2
DATA (WRITE)
DATA (READ)
RESPONSES: Q, X
MODULE
CRATE CONTROLLER
"L" LINE
SERVICE REQUEST, OR INTERRUPT
2771A6

FIG. A-2



7401
$\overline{N}$
$\overline{F1}$
$\overline{F2}$
$\overline{F4}$
$\overline{F8}$
$\overline{F16}$
$\overline{A1}$
$\overline{A2}$
$\overline{A4}$
$\overline{A8}$
N·F(0)·A(0)
D1
D2
D3
D4
$\overline{R1}$
$\overline{R2}$
$\overline{R3}$
$\overline{R4}$
$\overline{X}$
$\overline{Q}$
2488A11

FIG. B-1

$$(D_n)_{t+1} = (W_n)_t$$

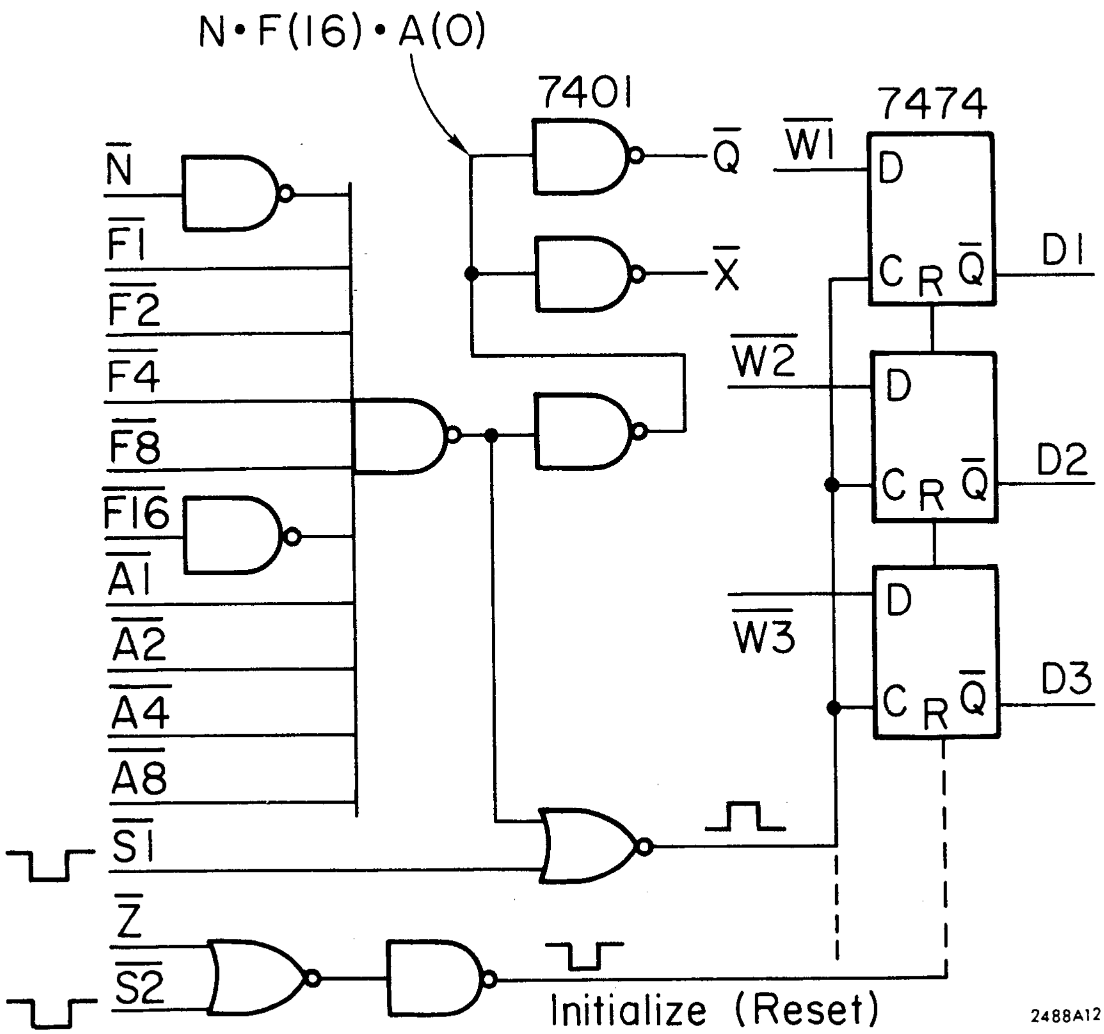
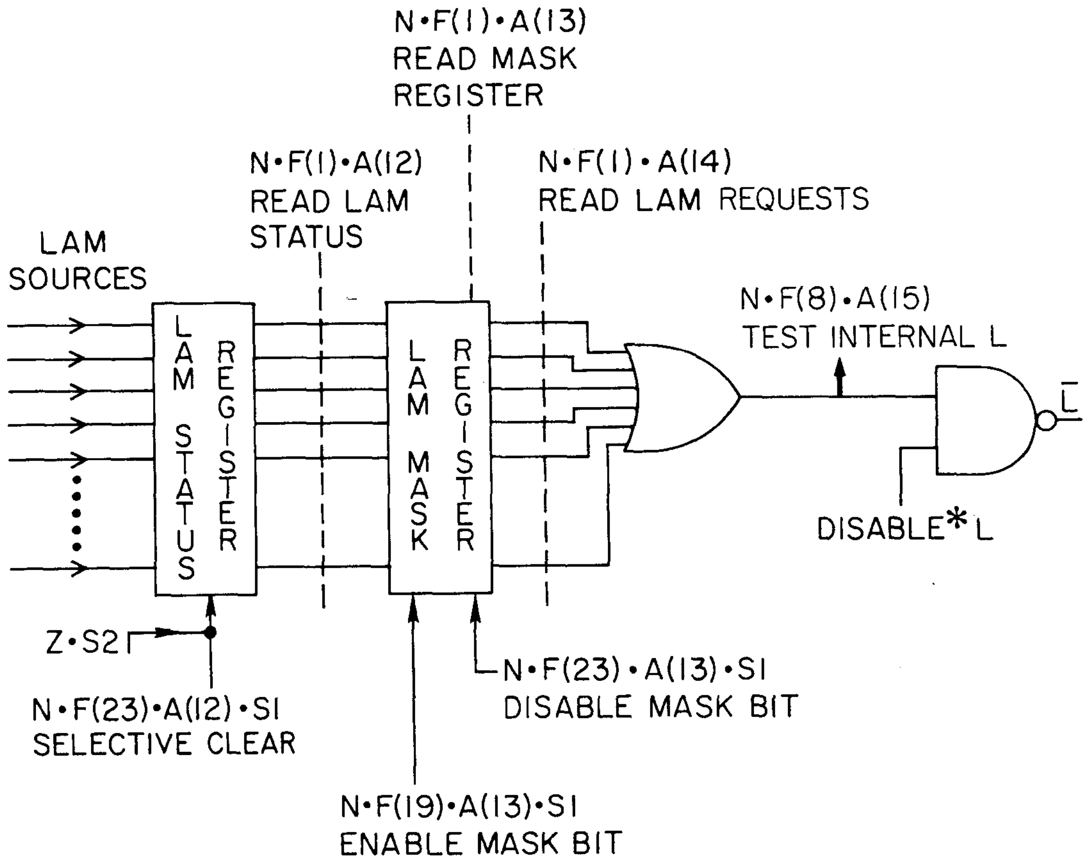


FIG. B-2



*IT IS REQUIRED TO DISABLE THE L SIGNAL WHEN RECEIVING A COMMAND THAT WILL CLEAR THE L SIGNAL. 2488A25

FIG. B-3