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TELEMETRY TEST METHODS

Final Report

J. L. Bowers, Project Leader

Project Team:
D. L. Bullard
T. R. Schelp

Published April 1978

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TELEMETRY TEST METHODS

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April 1978

Prepared by J. L. Bowers, D/134

A flexible test system is studied and proposed to provide an extensive evaluation and testing capability for telemetry products. A distributed computer controlled, modular unit test system using Computer Automated Measurement and Control (CAMAC) standard hardware and compatible software is selected because of its flexibility of application and long term cost effectiveness.

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SUMMARY

A flexible electronic product test and evaluation system is proposed. A study was performed to determine how increasingly complex joint test assembly (JTA) telemetry systems could be effectively evaluated during development and after first production units were built. A primary requirement was that this system remain flexible with respect to configuration and mission and that it be easily maintained. In addition, the system must be upgraded easily as old product requirements and definitions are replaced by new designs.

Concepts for a test and evaluation system were discussed with other ERDA contractors (LASL, LLL, SLL, SLA). As a result of these discussions, and an extensive literature search, the objective was determined to be realizable through the application of a computer interface standard such as Computer Automated Measurement and Control (CAMAC) which is outlined in IEEE Standards 583, 595, 596, and 683. The CAMAC standards permit independent instrumentation elements to be assembled into a compatible system.

As a result of this study, it was concluded that the construction of such a system would involve the investment of considerable funds and manpower and that the cost effectiveness of the system would be dependent upon its utilization and management. Because of the high initial cost of the complete system and the technical risk involved versus the advantages of the system, it was decided that the entire system would not be built. The CAMAC standard and the information developed presently is being applied to the construction of a microprocessor-controlled CAMAC-based evaluation system to test JTA neutron detectors. The study also demonstrates how the use of computer interface hardware standards can reduce requirements for specially designed test equipment for each application.

DISCUSSION

SCOPE AND PURPOSE

Joint Test Assembly (JTA) telemetry development and early production is characteristically fluid with respect to product definition while demanding unusually compressed time scales for product delivery. After JTA designs become stable, information is often needed which requires special testing and evaluation of production assemblies.

Test equipment is not usually available until the first production unit is built, primarily because stable product specifications are not available to design test equipment sooner.

Earlier JTA telemetry designs could be tested adequately with manual and open set-up methods during the development phase. With more basic electronic designs, the collection and analysis of large amounts of test data was not required; but as equipment data lists expanded, JTA telemetry designs became more complex. More sophisticated telemetry product required collection and processing of large quantities of development data without which product failures could not be accurately analyzed or prevented. A flexible test and evaluation system was proposed and studied to fill this need.

The multiplicity of JTA product definitions and the relatively small production quantities of each cause disproportionately high test equipment costs. As an improvement to this high tooling burden, the application of the same approach to production testing was considered and became a project goal.

ACTIVITY

A study was initiated to find the most appropriate system to meet the requirements for a development and production organization that supports paid order development work and special production evaluation as well as production test requirements not satisfied by conventional acceptance equipment.

Initial efforts included the review of a multipurpose laboratory test system in design and construction at Sandia Laboratories in Livermore, California (SLL). A similar concept was used for the design of a multipurpose test system at Bendix to provide, as an initial application, a laboratory test capability for terminal data analyzers (TDAs) in development. This system, a logic circuit analyzer, was to incorporate features similar to the test system at SLL. Computer control of the electronic instruments was studied and the design of a TDA bit train storage

unit was started. A completed prototype of the bit train storage unit was used to analyze development data on TDAs.

A review of results using the logic circuit analyzer indicated this same type of test capability could be expanded for use on other JTA products such as neutron detectors, signal conditioners, and telemetry subassemblies. It was recognized that carefully executed systematic approaches would be needed to manage the necessary complexity while providing the flexibility for assemblies on a variety of current and future products.

As these requirements were being evaluated, personnel at other ERDA contractors (SLL, SLA, LLL, LASL) were instrumental in recognition of a computer interface standard (CAMAC) which could contribute to meeting the Bendix objective (Appendix A).

A literature search (Appendix B) revealed wide application of CAMAC standards in certain fields such as nuclear research, medical electronics, and industrial process control. Flexibility and economics were the primary reasons for applying these standards in fields beyond the initial use in nuclear research. CAMAC permitted a significant reduction of recurring engineering design and system fabrication costs.

The CAMAC standard (IEEE 583) endorsed by ERDA as TID-25875 and the general purpose interface bus (IEEE 588) were both investigated. The CAMAC standard represented the more versatile of the two because it could accommodate instruments designed for IEEE 588 and also accommodate more varied data formats and higher data rates than IEEE 588.

System Description

A test system design was developed. A design philosophy was adopted having the following objectives.

- Flexibility: Instruments shall be organized into modules (functional units) based on function and application (Figures 1 and 2).
- Reconfiguration: The system shall be capable of use in any combination of a set of functional units. The functional units are to be capable of stand alone manual operation.
- Computer Control: Digital control of the functional units shall be compatible with CAMAC Standards TID-25875, TID-25876, TID-26448, TID-25877, IEEE 583, IEEE 595, and IEEE 596.

Figure 2. CAMAC System Design

- Signal Lines and Product Connection: Signal lines may be connected to the product directly from the instrument or functional unit patch panel or a set of CAMAC modules which comprise the product interface. A hybrid combination of product connection techniques is to be permitted.
- Software: Use high level language for man-to-machine interface and ease of programming. Use assembly language for a subroutine library of instrument handlers.

Functional Unit Descriptions

Computer Control Unit

The computer control unit (CCU) (Figure 3) is used for command and control of the system functional units via the CAMAC branch highway.

The CCU contains a PDP-11 computer with the following features:

- 64-K core memory,
- 2.4 million word disc memory,
- Hardware memory management,
- Hardware multiply and divide,
- Hardware floating point package,
- Real time clock,
- Hardware bootstrap loader,
- Four-level priority interrupt,
- Power fail and auto restart,
- Dual cassette tape,
- Industry compatible 0.5-inch digital tape,
- Hard copy terminal,
- Storage terminal, and
- CAMAC system crate.

The CCU provides system control through software support of assembly language or Fortran programming. The software languages (assembly language [Macro] and Fortran) which are supported by

Figure 3. Computer Control Unit

a disc based operating system (RSX-11-D) allow the creation of an instrument handler subroutine program library which can then be accessed and utilized by a mainline program written in Fortran. The user may access various mainline software media, including another disc.

Other computers are suitable and can be accommodated by the CAMAC Standard Interface.

The CAMAC branch highway is accessed through the CAMAC System Crate which consists of:

- A powered CAMAC crate,
- A system crate controller module,
- A PDP-11 unibus interface module, and
- Positions for a maximum of 10 parallel branch highway or 6 serial highway driver modules.

Each parallel branch highway driver can communicate with a maximum of 7 other CAMAC crates, giving the single system crate the capability of controlling from 1 to 70 other CAMAC crates. This feature provides the inherent flexibility in the system configuration.

The parallel branch highway is a cable consisting of 66 twisted pair wires with connectors as specified in the CAMAC standard. The branch highway cable is available commercially in any practical length.

Data is transmitted on a 24-bit data bus within the parallel branch highway.

The serial highway uses either a bit-serial or a byte-serial mode for transferring data and control information. Up to 62 crates can be accommodated for each serial driver, giving the single system crate the capability of controlling from 1 to 372 other crates.

The serial highway is intended to complement the parallel branch highway described in TID-25876 and IEEE 596-1976. The serial highway is attractive in applications that the parallel branch is not designed to cover, including cases where long distance links between crates are necessary. However, the time required to perform a complete operation, which includes a dataway cycle, will generally be longer on a serial system than on a parallel branch. The parallel bus was selected to be used in the proposed system primarily because of the high data rate requirements of JTA systems.

More than one highway can be used to operate separate groups of functional units, thus allowing program development and testing to be done through the multitask, multiuser oriented operating system RSX-11-D. Using the computer control unit in this manner assures efficient use of the equipment and of the system software capability.

Waveform Monitor Unit

The waveform monitor unit (Figure 4) permits waveform analyses such as pulse rise time versus fall time and peak amplitude, and provides the ability to visually display the shape of a transient waveform for observation.

The waveform monitor unit consists of a high speed transient digitizer (Tektronix R7912) with a video display or equivalent equipment. Digital interface of the digitizer is through a CAMAC module made by Tektronix. A Biomation 8100 transient recorder could be substituted or added to the waveform monitor unit, depending on requirements.

Signal/Monitor Unit

The signal/monitor unit (Figure 5) supplies signals required to perform product tests and monitors signals generated by product during testing.

Signals generated and monitored by the signal/monitor unit are available from both the instrument front panel and through the signal unit patch panel. Signal lines may be connected from either of these locations to the product interface unit or directly to the product, depending on signal integrity requirements or convenience. Digital control of each instrument is provided through a CAMAC interface module which can accommodate instruments not designed for the IEEE 588 interface bus. The availability of an IEEE 588 interface bus CAMAC module will also make all interface bus instruments compatible with the CAMAC Standard.

Special instruments which must be custom made or are not commercially available can be fabricated as CAMAC modules, incorporating the instrument and its CAMAC interface into one compact piece of hardware.

Power Supply Unit

The power supply unit (Figure 6) supplies product under test power. Each power supply is under computer control through a CAMAC interface.

A power patch panel/relay drawer is supplied to connect power to the product interface unit or directly to the product. The

Figure 4. Waveform Monitor Unit

power patch panel/relay drawer also contains load and current viewing resistors (CVR) for power supply output voltage and current monitoring before and during product tests using software control.

The power supply unit also contains a digital voltmeter (DVM) and a DVM relay tree used under software control for a power supply precheck subroutine. The precheck is part of the power supply software handler routine. This routine exercises the power supply and measures its output with and without loads before the output is connected to the product under test. This ensures correct power application.

Radio Frequency Unit

The RF link unit (Figure 7) monitors the performance of a telemetry (TM) set or transmitter. Data can be monitored and analyzed by using the RF link unit in conjunction with the data record/decom unit. Time domain multiplex or frequency domain multiplex data can be decommutated. The computer control unit would format data and analyze real time or recorded pulse coded modulated (PCM) or frequency modulated (FM) data.

Figure 5. Signal/Monitor Unit

Data Record/Decommutation Unit

The data record/decom unit (Figure 8) consists of an analog tape machine (Ampex FR-1900), time code generator, search and reader units, and a PCM and FM telemetry ground station front-end system. The front-end system consists of a signal conditioner/decom-mutator for PCM data and a set of constant bandwidth/proportional

Figure 6. Power Supply Unit

Figure 7. RF Link Unit

bandwidth discriminators for FM data, including a discriminator for tape speed compensation. Digital interface of the analog tape machine is provided by a set of CAMAC modules.

The primary functions of the data record/decom unit include, but are not limited to, the following uses:

- Formatting or analyzing digital tapes from either analog tapes or product hardware when used in conjunction with the computer control unit and its direct memory access (DMA) port, and
- Accepting data from the RF link unit when performing RF data transmission checks of a TM unit or TM transmitter.

Figure 8. Data Record/Decom Unit

The data record/decom unit also includes provisions for using equipment and techniques to decommutate high speed terminal data which were developed earlier.

The data record/decom can also be used for quick-look data analysis using the decimal displays and printer (HP-5050).

The system will provide the capability for real time recording and analysis of TM data taken during environmental testing.

Neutron Generator Unit

The neutron generator unit (Figure 9) consists of a pulsed neutron source and a lead probe counting system. This unit could provide test capability for JTA neutron detectors as a stand alone unit under microprocessor control or--controlled by the computer control unit--for system tests involving neutron detectors. This unit performs high speed analog to digital (A/D) conversion of neutron flux rate waveforms for computer analysis and for sensitivity calibration of neutron detectors.

A microprocessor would act as a peripheral processor and supply summary data for plotting, data logging, and statistical analysis. As a stand alone unit, the neutron generator unit would be capable of performing mathematical operations and basic statistical data reduction for calibration and evaluation of JTA neutron detectors.

Product Interface Unit

The product interface is a set of commercially available standard or specially designed CAMAC modules. The modules, fixturing, and cables must be supplied by the user.

The product interface unit (Figure 10) consists of a rack containing two powered CAMAC crates.

A basic set of CAMAC modules will be part of the product interface unit to provide functions required by the tester and the product. These modules perform signal switching and attenuation used in programming tester instruments, A/D and D/A conversion, and general purpose program input/output transfer functions for monitoring the product or controlling the product test fixture.

Cost Evaluation

A cost estimate and evaluation were performed and are contained in a financial/manpower project sketch (PS 06984788-002). The estimated material cost is \$373,000 with a labor estimate of 9.08 man years. A summary is provided in Figure 11 and Table 1. All estimates are in FY1975 base dollars.

Figure 9. Neutron Generator Unit

Figure 10. Product Interface Unit

This evaluation indicated there would be a high initial labor investment and equipment expense, and considerable continuing cost of operation and maintenance. Additional cost would be required to reconfigure the system for testing different products in addition to the replacement of obsolete equipment.

ACCOMPLISHMENTS

A flexible telemetry product evaluation and test system design was proposed, studied, and evaluated for effectiveness and cost

Figure 11. Departmental Labor Estimates

Table 1. Funding Estimate Summary

Equipment	Material
Computer Control Unit	\$ 69,000
Waveform Monitor Unit	26,000
Signal Monitor Unit	59,000
Power Supply Unit	35,000
Radio Frequency Link Unit	24,000
Data Record/DECOM Unit	108,000
Neutron Generator Unit	38,000
Product Interface Unit	14,000
Total	\$373,000
Total Cost Estimate*	\$373,000

*FY1975 base dollars

impact. The system could provide an effective evaluation and test capability with quick turn-around times for use on many electronic products. It was decided that the entire system would not be built because of the high initial cost, the technical risk involved (such as mean time between failure and system downtime), and because the effectiveness of this system depends upon unknowns regarding its utilization and management.

The CAMAC standard and information developed during this project is presently being applied to the construction of a microprocessor-controlled CAMAC-based evaluation system to test JTA neutron detectors (the neutron generator unit). This study also examines the use of computer independent interface hardware and software standards (CAMAC) to reduce the expense of specially designed test equipment for each application.

FUTURE WORK

No further work on this project is planned as formal process development. However, further development of this test system should be studied and undertaken when conditions and needs dictate.

Appendix A

CAMAC OVERVIEW

The nonproprietary CAMAC (Computer Automated Measurement and Control) system standard defines an assemblage of modular units and the dataway which interconnects them. Dimensions are specified for the crates (the containers for the modules) and the plug-in modules which supply the various logic functions contained within the system. Also detailed are the interconnection arrangement, including the sockets and the interconnecting data highway.

These standards permit mechanical and electrical compatibility between equipment supplied by different sources. The CAMAC standard was developed as a computer controlled second generation of the nuclear instrumentation module (NIM) family. By utilizing the CAMAC standard in the design and construction of an instrumentation system, much of the unnecessary and routine detail of equipment redesign and modification can be alleviated by allowing the use of the equipment mainframe concept (similar to an oscilloscope with plug-in modules). The mainframe concept can be carried through to the design of production and acceptance test equipment which can use plug-in CAMAC modules designed and developed along with development product.

By developing product test capability this way, significant long term savings will be realized as a result of standard hardware package designs and interface specifications. One objection to adopting a standard is that it restricts the designer's creativity. Investigation of the specification will reveal that the CAMAC standard provides the specification of the instrument interface only. The rest is left to the designer.

CAMAC was created to provide flexible instrumentation that can be reconfigured easily and not be dedicated to a specific task. The concept manifests itself by the fact that CAMAC systems can be easily adapted to different computers and controllers. This allows a CAMAC system to be updated to a new computer, if required, without the expense of massive and uneconomical interface redesign and construction. This flexibility was a requirement at all the major nuclear laboratories where experiments utilized many different types of computers.

CAMAC is an international standard originated at the major European nuclear laboratories. After its introduction, the United States Atomic Energy Commission reviewed and endorsed its use.

Many United States vendors are presently producing CAMAC instruments and hardware. These vendors manufacture everything from blank sheet metal enclosures, components, and crates for modules

to complete instruments (programmable power supplies, pulse generators, attenuators, counters, and delay generators) meeting the CAMAC specification.

The advent of the CAMAC instrumentation standard lends flexibility to an instrumentation system that is required for development of product before and during production.

As a result of the incorporation of the CAMAC standard, an instrumentation system will remain flexible and adaptable over a period of years with the capability of being modified and reconfigured with minimum cost to the user. This feature will allow a system to remain current and eliminate the usual plight of obsolescence associated with dedicated test equipment.

The use of CAMAC has been proposed to NASA by the Bendix Aerospace Systems Division for use on the space shuttle. Other companies are considering the use of CAMAC instrumentation in related process control and instrumentation applications.

NIM-CAMAC MANAGEMENT AT NATIONAL FACILITIES*

NIM and CAMAC equipment is extensively used at national laboratories. Visits were made to the National Science Foundation (NSF) National Accelerator Laboratory (NAL) at Batavia, Illinois, the NSF Kitt Peak National Observatory (KPNO) at Tucson, Arizona, and the Los Alamos Meson Facility (LAMPF) recently renamed the Clinton D. Anderson Meson Physics Laboratory at Los Alamos, New Mexico. All of these facilities maintain NIM-CAMAC pools for experimenter use, and their experience would be useful in establishing a NASA pool for Space Shuttle Sortie experiment payloads.

The NIM-CAMAC pools at NAL and LAMPF were similar as they both support high energy physics experiments. NAL is older than LAMPF and their pool is about 10 times larger. The NAL pool is \$5 million worth of NIM-CAMAC equipment compared to the \$0.5 million in the LAMPF pool. LAMPF also maintains a separate pool for in-house researchers, but as most experimenters have a LAMPF experimenter on their team, the equipment becomes intermixed. Both laboratories loan the equipment to the experimenter during the experiment buildup and he keeps the equipment until his experiment is completed. This period can be from 3 months to 2 years.

*Reprinted from *Feasibility Study of Common Electronic Equipment for Space Shuttle Sortie Experiment Payloads*. Ann Arbor, Michigan: Bendix Aerospace Systems Division, Final Report BSR-4142, June 1974.

The management practices at the two facilities are slightly different. At NAL, after an experimenter receives approval for his experiment he prepares a list of the equipment he needs. The cost of the equipment and the duration of the equipment loan are established and he is issued a contract from NAL for the dollar amount of the equipment over the duration of the experiment. The experimenter is at liberty to change the mix of equipment he actually uses so long as the dollar amount and duration do not change. Small overruns (approximately 10%) in dollar amount and duration are tolerated. Large overruns must be renegotiated.

At LAMPF, the practice is to negotiate the list of equipment and hold the experimenter to his list. If an experimenter's requirements change, he has to renegotiate his needs. Each experiment is given a priority, and a high priority experiment can take equipment from a low priority experiment. Priorities change with time and usually become higher the closer the experimenter comes to running his experiment in the accelerator.

The NAL practice offers the experimenter more flexibility but requires a larger pool since needs are not controlled. Both facilities plan to expand their pools. Currently NAL supports about 30 experimenters and LAMPF supports 16 number one priority experiments and 11 lower priority experiments.

The Kitt Peak operation differs considerably from that used at high energy accelerator facilities. Most astronomers depend on Kitt Peak to provide standard instruments for their observation. Thus, the hardware remains reasonably constant. The variation from experiment to experiment is in data collection. Kitt Peak will vary real-time clocks, pulse counting and analog readout modes, scaler speed and capacity, and analog dynamic range and digitizing accuracy between experiments. A typical time to set up an experiment and check out new software is 3 hours. Installation time in the telescope requires about 2 hours. Typical duration of an experiment is 3 days.

Kitt Peak uses CAMAC exclusively to interface the telescope instruments to a computer. Each telescope installation requires only one crate. A typical crate configuration is slots 1-12 dedicated telescope control module; slot 13, input register; slot 14, output register; slot 15, quad scaler; slot 16, up/down counter; slot 17, eight-channel gate; slot 18, dual-channel timer; slot 19, digital oscillator; slots 20-21, display panel controller; slot 22, Dataway display; and slot 23, LAM grader. The first 12 modules are required for the telescope control and are not changed with instrument changes. The remaining modules are varied to interface different instruments. Kitt Peak has 12 crates, 11 for active use and one as a test bed in the Tucson laboratories.

Kitt Peak has developed their own approach for cabling. Cannon 36-pin ribbon connectors have been added to the back of each CAMAC module. These connectors are used for all input connections rather than front panel connectors. The Cannon connectors are wired into a patch panel, which is also connected to an instrument connector panel using heavy duty AN-type connectors. The instruments are connected by means of the AN connectors and the patch panel reassigns the wire routing between different instruments and the CAMAC module.

Appendix B

CAMAC LITERATURE

During this project, an extensive survey was conducted of the literature available on the CAMAC system. Much of the literature turned out to be redundant, but the survey did uncover a number of documents which should be required reading for anyone involved with CAMAC.

Significant literature is listed on the following pages. Complete bibliographic references have been provided wherever possible. Most of the literature is available through any technical library. Vendor literature is available through the firms involved.

SELECTED PUBLICATIONS

Readers with limited time may be required to confine their research to a few publications. The following listing may prove helpful.

CAMAC: A Modular Instrumentation System for Data Handling; Description and Specifications. ERDA Report TID-25875 and EURATOM Report EUR 4100e, 1972.

CAMAC: Organization of Multicrate Systems. ERDA Report TID-25876 and EURATOM Report EUR 4600e, 1972.

Supplementary Information on CAMAC Instrumentation System. ERDA Report TID-25877. Also published as supplement to *CAMAC Bulletin*, Issue 6, March 1973.

CAMAC Serial System Organization: A Description. ERDA Report TID-26488 and ESONE Report ESONE/SH/01.

CAMAC: Specification of Amplitude Analogue Signals Within a 50 Ω System. ERDA Report TID-26614 and EURATOM Report EUR 5100e, 1974.

CAMAC: The Definition of IML, A Language for Use in CAMAC Systems. ERDA Report TID-26615 and ESONE Report ESONE/IML/01.

CAMAC Bulletin. A Publication of the ESONE Committee and issued three times annually by EURATOM.

Proceedings of the 1974 Meeting of IEEE Industry Applications Society. IEEE Conference Record 74CHO 833-41A (Part 1).

"CAMAC Tutorial Issue." *IEEE Transactions on Nuclear Science*, NS-20, Number 2, April 1973.

"Proceedings of the 1973 Nuclear Science Symposium." *IEEE Transactions on Nuclear Science*, NS-21, Number 1, February 1974.

"Proceedings of the 1974 Nuclear Science Symposium." *IEEE Transactions on Nuclear Science*, NS-22, Number 1, February 1975.

Release of the various CAMAC specifications as IEEE Standards has continued with the pertinent supplementary information and amendments integrated into the documents.

Title	IEEE Standard	Remarks
<i>Modular Instrumentation and Digital Interface System (CAMAC)</i>	583-1975	Supersedes TID-25875 plus pertinent portions of TID-25877.
<i>Serial Highway Interface System (CAMAC)</i>	595-1976	Supersedes TID-26488 and amendments thereto.
<i>Parallel Highway Interface System (CAMAC)</i>	596-1976	Supersedes TID-25876 plus pertinent portions of TID-25877.
<i>Block Transfers in CAMAC Systems</i>	683-1976	Supersedes TID-26616.

GENERAL

The following articles and papers cover a variety of CAMAC applications and may be selectively reviewed for detailed information on specific subjects.

"The Revised CAMAC Specification EUR 4100e (1972), by R. C. M. Barnes. *CAMAC Bulletin*, Issue 4, July 1972, pp 6-8.

"CAMAC Dataway--Branch Highway Timing Relationship Via the Crate Controller," *CAMAC Bulletin*, Issue 3, March 1972, pp 7-8.

"CAMAC Crate Controller Type A," by S. Dhawan. *IEEE Transactions on Nuclear Science*, NS-18, Number 2, April 1971.

CAMAC: The Definition of IML, a Language for Use in CAMAC Systems. ERDA Report TID-26615.

Computer Organization, by I. Flores. Englewood Cliffs, New Jersey: Prentice-Hall, 1969.

Standard Nuclear Instrument Modules (Specifications of the NIM System). USAEC Report TID-20893, Revision 3, December 1969.

"Proceedings of the 1969 Nuclear Science Symposium." *IEEE Transactions on Nuclear Science*, NS-17, Number 1, February 1970.

Proceedings of Skytop Conference on Computer Systems in Experimental Nuclear Physics. USAEC Report CONF-69031, October 1969.

"Some Thoughts on the Data Acquisition Problem of High-Energy Physics Experiments," by F. A. Kirsten. *Proceedings of the 1969 Nuclear Science Symposium, IEEE Transactions on Nuclear Science*, NS-17, Number 1, February 1970, pp 452-457.

"Versatile CAMAC Crate Controller for Computer-Based Data Acquisition Systems," by J. E. Eicholz, *et al.* *IEEE Transactions on Nuclear Science*, NS-18, Number 1, February 1971, pp 292-298.

"On the Design of CAMAC Branch Drivers," by S. Dhawan. *IEEE Transactions on Nuclear Science*, NS-19, Number 1, February 1972, pp 721-725.

"CAMAC Multi-Microprogrammed I/O Processor," by J. A. Buchanan and H. V. Jones. *IEEE Transactions on Nuclear Science*, NS-19, Number 1, February 1972, pp 682-688.

"Versatile PDP-11 CAMAC Crate Controller for Nuclear Data Acquisition and Processing," by H. Halling, *et al.* *IEEE Transactions on Nuclear Science*, NS-19, Number 1, February 1972, pp 699-703.

Microprogrammed Branch Driver (MBD) for a PDP-11 Computer, by L. P. Biswell and R. E. Rojala. LASL Report LA4916, Los Alamos (New Mexico Scientific Laboratory), April 1972.

Autonomous Transfer Controller for PDP-11 Type 081, by F. Iselin, *et al.* CERN-NP CAMAC Note 40-00, 1972, CERN, Geneva, Switzerland (unpublished).

Feasibility Study of Common Electronic Equipment for Shuttle Sortie Experiment Payloads. Ann Arbor, Michigan: Bendix Aerospace Systems Division Final Report BSR-4142, June 1974.

"The CAMAC Story," *Computer Magazine*, May-June 1971.

"The CAMAC Scheme of Electronic Modules." *Physics Bulletin*, Volume 20, September 1969, pp 366-369.

IEEE TRANSACTIONS

The following material was published in various issues of *IEEE Transactions on Nuclear Science*.

The following are from Volume NS-20, Number 1, February 1973

"CAMAC High Resolution Time Interval Meter," J. Wiedwald.

"CAMAC Magnetostrictive Readout System Using Schottky Memories,"
B. Bertolucci.

"CAMAC: A Review and Status Report," L. Costrell.

"CAMAC Specification," F. Kirsten.

"CAMAC Fundamentals and Specifications Status," Panel Discussion.

"A CAMAC System for Remote Data Acquisition," R. Furst and
J. Wiedwald.

"Versatile Modular Readout System for CAMAC Scalers," D. Horelick.

"Standard Software for CAMAC - S. Dhawan and R. F. Thomas, Jr.

A Long Distance CAMAC Branch Via Data-Link and Microprogrammed
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