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A Brief Review of Nuclear Electronics Standards*

Past, Present and Future

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Abstract

Modular Nuclear Instrument Standards have played a key role in U.S. Department of Energy National Laboratories and similar scientific laboratories worldwide for more than three decades. The scientific and engineering efficiency and economic benefits have been well documented. Standards are constantly evolving with the introduction of new technologies and the present is a time of rapid change. This paper gives a brief overview of past developments and attempts to identify areas of possible opportunities for renewed standardization efforts to meet future challenges.

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1. A BRIEF HISTORY OF HIGH ENERGY PHYSICS LABORATORY MODULAR ELECTRONICS STANDARDIZATION[1]

Modular electronics standardization efforts began in the late 1960's because laboratories were making very large investments in high-speed detector front-end electronics and data acquisition systems that were totally incompatible both physically and electrically. NIM (Nuclear Instrument Module) standardization began in the nuclear physics community. In 1964, the Lawrence Berkeley Laboratory (LBL), Lawrence Livermore National Laboratory (LLNL) and Oak Ridge National Laboratory, together with the National Bureau of Standards, collaborated to produce the first prototypes and became the first users. NIM found its first market entry through companies producing scintillation and semiconductor detectors and radioactivity measurement instrumentation. ORTEC was the first to market commercial NIM products and was soon followed by several other manufacturers. Before long NIM found a ready market in the growing High Energy Physics (HEP) community, which in turn drove the fast logic module industry toward compliance. LeCroy, an upstart new company, was the first to adopt the NIM standard for its introductory series of nanosecond logic modules. Others followed as all the major HEP Laboratories began to specify NIM compatibility[2].

CAMAC[3] quickly followed as the first microprocessors fueled development of standard controllers. The first standardized crate with a data bus to support high-density digital modules became an equally successful story. For a time much debate ranged over the suitability of CAMAC for analog electronics because of the noise of digital circuits. Except for the most demanding analog requirements, CAMAC proved well adaptable to the bulk of needs. The first applications of CAMAC in North America included both data acquisition and control of accelerators and large telescopes. NIM and CAMAC have coexisted all these years, but in HEP CAMAC eventually took over most of the functions for front-end electronics that originally existed only in NIM. NIM later received attention from the standards committees in the form of a data bus of its own. CAMAC continued to receive upgrades of auxiliary buses and user discretionary options as new applications demanded. Both parallel and long distance serial controllers for interconnecting crates were developed and successfully served hundreds if not thousands of experiments.

A particularly difficult area of standardization was software. Confined to the problem of collecting and moving data, software was quite successful in developing and maintaining a set of standard protocols. At the module level, functionality varied so much between modules of different manufacturers, and modules that were custom built in laboratories, that the driver software for a data collection of mixed modules inevitably required

[1] Note that this paper is written primarily from the vantage point of the High Energy Physics community. I do not attempt to give a balanced view of the total impact of the standards being discussed on other communities.

[2] Private communication, L. Costrell of NIST, organizer of the NIM Committee, provided this early historical perspective.

[3] Computer Automated Measurement And Control was the English assigned to the palindrome that was invented in multi-cultural Europe. The symmetry was intended to symbolize two-way data transfer.

considerable customization. Overall, many experiments were well served by commercial software including the challenging CAMAC top end Branch Driver server software.

The HEP community intervened in this relatively placid scene to observe that the CAMAC bandwidth was constricting development of ever more dense data sets that were foreseen for future detectors, and in response an effort was launched by the laboratory engineering groups to develop yet another standard, FASTBUS. The advent of FASTBUS introduced a wider, faster bi-directional data bus at the crate level along with many features designed to take full advantage of the available bandwidth. It also introduced a much larger form factor with higher power capacity and a powerful auxiliary bus that allowed modules to be plugged into a rear upper backplane. This area became used for a variety of customized needs such as trigger logic where passing of data to a next level of decision making required fast inter-module communication that could be independent of the main bus. Both analog and digital functions were supported and a large I/O bandwidth and memory capacity, as required, was achieved. Software standardization efforts were ever more strenuous due to the complexity and number of options possible with this new structure. The flexibility of FASTBUS modules exceeded the fondest expectations of the most adventuresome engineers and physicists, but at a cost in complexity.

FASTBUS also reached the commercial world, finding its most suitable applications among high powered digital processing modules and data movers, and both standard and quite specialized amplifier, ADC and TDC modules. The cost of entry into FASTBUS was considerably higher than its predecessors, and the investment in engineering design in a typical FASTBUS module was also higher due to the huge amount of available real estate, often demanding a design team rather than a single designer. However, the per-channel costs were actually significantly lower than CAMAC because of the much higher density. Technically FASTBUS met the goals of its inventors and major HEP users. However, its market niche was considerably narrower than either CAMAC or NIM due to the high degree of specialization of the architecture.

Just as FASTBUS was maturing, custom chip technology was enabling more and more of the modular electronics to be mounted directly on detectors, which began to be pursued aggressively to minimize expensive cable plants as well as to gain a more hermetic overall detector. One of the earliest detectors to exploit the new capabilities was the SLAC Large Detector (SLD) in which all front ends for major subsystems including inner trackers, drift chambers, liquid argon (LAr) calorimeters, Cerenkov and Muon detection were mounted on the detector. Data were highly multiplexed and brought out via coax and fiber optic cables to receivers in FASTBUS. The latter racks were mounted directly atop the detector and not in a separate room as formerly.

All large detectors are now built in this fashion, which has limited the role of the original modular standards and created a new situation where the bulk of detector electronics has few if any standards that are shared among many users and laboratories. This situation ensues because new detectors are highly specialized and geometrically constrained, and each demands special form factors if not special circuits at the front end. Therefore, using

the LHC as the current example, entire systems of packaging are being invented for each new detector by large worldwide teams of engineers and physicists. Certainly there is much sharing of knowledge among various groups, but it is informal and appears not organized in any deliberate sense as a standards effort. A direct impact is that the earlier commercial suppliers of modular front-end equipment have been essentially dealt out of new business opportunities. Those who have benefited have been a mixture of providers of custom chip services, board and hybrid manufacturers, and to a much lesser extent vendors of traditional modules and newer VME implementations.

Two more recent standards efforts are VMEp (VME for Physics) and FAST CAMAC. VMEp is an inter-laboratory initiative to extend the features of VME to include physics features. This design has enlarged bandwidth and scanning protocols, a higher quality backplane, better shielded modules, better matched and higher capacity shielded connectors, and crates that are backward compatible with standard VME. The objective is a generation of VME that appears to compete directly with FASTBUS but will enjoy support by a much larger manufacturing community. Since this development is very new its commercial success is not yet measured.

FAST CAMAC is the invention of a small U.S. consortium of Yale University (S.Dhawan) and LeCroy and Jorway companies. The goal has been to extend the utility of CAMAC with modules that run compatibly on existing crates but with a faster protocol driven by a modernized FAST CAMAC controller. It is a clever strategy that ultimately appeals to small users who wish to extend the life of an existing system or inventory. It appears to have a niche market appeal to small experiments and quickly configurable acquisition and test systems, using the familiar CAMAC platform. Currently it aims to integrate into PCs via the PCI bus, for which a controller is still unavailable.

In the Controls field these standards have had only modest impact. SLAC has probably exploited CAMAC for controls more than other laboratories, and even the most recent machine, PEP II, used CAMAC heavily, extending rather than replacing the current large system in place for the Linear Collider (SLC). The PEP effort required inventing several new CAMAC modules for accelerator control, mainly Beam Position Monitors, a Programmable Delay Unit precision timing module, and a Beam Abort System module for machine protection. Two other PEP II systems, Low Level RF and Longitudinal Fast Feedback, used the more recent VXI commercial platform, due to its compatibility with high performance processors, a large form factor and wider front panel favored for RF hybrid components and solid coaxial on-board cabling, and superior RF shielding properties. In other laboratories, VME has been the dominant instrument bus of choice for accelerator controls.

Meanwhile, on the detector front, in this same PEP II machine VME has supplanted FASTBUS as the platform of choice for the Detector (BABAR). Advanced design commercial crates and racks have been used with high success. The flexible form factor of VME, allowing very large cards comparable to FASTBUS, along with a broadly supported industry standard bus with considerably enhanced bandwidth compared with earlier versions, seems to spell the end of FASTBUS for new designs of the top layer of

the data acquisition system. Most of the front end electronics of course is routinely buried in or mounted on the detector, either in specialized subassemblies or simply bolted to power distribution busing and data/controls I/O.

2. WHAT ENABLED THE SUCCESSFUL LABORATORY STANDARDIZATION EFFORTS OF THE PAST?

The original standardization efforts starting over thirty-five years ago coincided with certain technology developments that made possible impressive economic and technical standardization advantages for experimenters and laboratories:

- Improved speed Silicon transistors replaced Germanium and more exotic devices that were used earlier to obtain fast switching speeds. Standard logic levels doubled and were able to drive more circuits at standard NIM levels.
- Silicon integrated circuits appeared on the scene to enable denser logic that became fast enough to take over many logic functions formerly possible only with discrete transistors. Channel density greatly increased and per-channel costs came down rapidly.
- Microprocessors appeared and enabled the development of modular controllers on a very compact form factor. More processing power began to appear closer to front end subsystems.
- The standards communities seized these opportunities in a unique collaboration with industry to produce viable and attractive hardware solutions in time to have major impact on new detectors being built in many laboratories at the same time.
- Sufficient manufacturers in both Europe and the U.S. were interested enough to collaborate on designs as well as to adopt the new tooling and pay the development costs to launch new products.
- The standards inventors (laboratories) did a good promotional job, including introducing prototype systems into experiments, holding short courses sponsored by IEEE and NBS in a number of key locations in the U.S. Annual conferences such as the Nuclear Science Symposium offered a venue for the promoters, industry and active experimenters to share results and generate further interest.
- The NBS (now NIST) in the U.S., ESONE in Europe, and the IEC all were instrumental in processing the standards through the various agencies including IEEE and ANSI as well as the above. Louis Costrell was and is the driving force behind these efforts, and his position in NBS, a part of the U.S. Department of Commerce, has been key to success of processing these and many other standards for the Nuclear Instrument and Controls community.

The truly unique accomplishment of the laboratory standardization efforts was that a relatively small niche market in physics was able to drive a standardization effort to commercialization more or less single-handedly. Most such efforts before and since were and are driven either by the Military or by various consortia of Industry. The latter is the normal means whereby industry competitors promote a solution for a group of products where the nature of the market demands functional compatibility. The physics market was just large enough to be able to accomplish this on its own, partly on the promise that

modular solutions would help companies sell products across a much broader market segment. This worked out to some degree for NIM and CAMAC vendors, but probably not at all for the more specialized and costly FASTBUS. However the leveraging concept may work out better for VME in its new ventures, since VME has significantly more manufacturers and a significantly broader market reach than any of the physics standards. This strength stems primarily from the broad acceptability of VME as the packaging standard for microprocessors and digital signal processors (DSPs) for systems vendors. High-powered workstations for computer aided design and analysis that use Motorola, TI and Intel products largely drive this market.

3. WHAT HAVE WE LEARNED ABOUT THE BENEFITS OF STANDARDIZATION?

One of the most obvious benefits of standardization in the laboratories was the improvement in efficiency of electronics engineers. Heretofore, each engineer faced with a design had to invent a package. The packages that existed in laboratories were large non-modular rack mounting boxes, the smallest of which was 1.5 inches high, 19 inches wide, and as deep as one wished to make it within the cabinet size, typically 24 inches maximum. The hardware was an industry standard, but totally unsuitable for physics experiments. The advent of a standard module, and a standard mainframe, was a tremendous advance for research that has not received due recognition. Engineers immediately had a ready platform for almost any design that was needed in a laboratory instrument. The standard became applied in many accelerator instruments as well as detector systems. Standard layout forms and CAD layout systems made many design decisions routine and eliminated painful reinvention.

A second major advantage was the Equipment Pool concept. Experiments could be built from a stock of standard modules, easily configured and dismantled, and easily reused by the next user. The inventory of equipment was used extremely efficiently, another great savings of time, effort and money.

A third major savings was in maintenance. Standard testing and tooling could be applied that made repair routine and efficient. Field repair was a simple swapping of a like unit. Automated test sets could be operated in a central repair depot to simplify troubleshooting. Again the largest savings were through the efficient leverage of skilled people.

The early proponents of these modular systems literally fought against the entrenched instrument manufacturing community, including the biggest names in the industry, on the merits of the modular approach. People from industry wrote articles denouncing the hair-brained physicists and engineers who thought these standards were viable, economical and the wave of the future. Although modular instruments are now widespread in many new forms, the small physics-spawned modular instrument community could not penetrate the larger markets dominated by the big players. During the economic hard times of the early 90’s, some of the top names in industry introduced or acquired lines of

modular instruments aimed at the measuring instrument, process control and industrial control fields, based on the VXI standard, an adaptation of VME to the Instrument community. Some such modules now appear as stand-alone instruments, such as oscilloscopes, as well as in systems configurations. During the 90's, many other modular instruments have sprung up, most notably those that plug into established modular frames such as the IBM PC. Meanwhile, the original CAMAC vendors are finding dried up markets for many products, while the largest vendor appears to have abandoned the modular physics instrumentation markets in favor of standard high-end bench-top instruments.

4. DO STANDARDS HAVE A FUTURE IN PHYSICS INSTRUMENTATION?

To attempt and answer, we need to look at current developments and trends, while keeping in mind the principles that motivate standardization in the first place. The principles that are always valid are:

1. Standards should be technically and economically defensible to the customer.
2. Standards should show clear advantages in the efficient utilization of design engineers.
3. Standards should result in a technically superior product over one made by an individual laboratory team.
4. Standards should enhance ease of replacement, in-situ diagnostics and off-line repair of field replaceable units.
5. Payback time for a standards investment should be measurable, e.g. <3 years.
6. Special standards efforts should be undertaken only if existing commercial offerings are inadequate or cannot be easily adapted, or lack the desired compatibility and interchangeability.
7. Standards efforts require a critical mass of proponents who also represent real users and major projects purchasing power.
8. Standards efforts require cooperation with industry from inception of design through to finished, delivered product.
9. The useful life of a standard should be judged in relation to the lifetime of the expected usage (e.g. accelerator or detector) and the likelihood that obsolescence of parts or requirements for increased performance will force earlier replacement.
10. Standards need to embody a platform that can be upgraded to new electronics without rendering the basic standard obsolete.

The last point is critical. Electronics that are now used in detectors have moved at a rapid pace. *Standards have to be adaptable to changing technology.* The old standards went through many adaptations successfully, which explains their longevity, but the pace has quickened. Some recent key developments are:

1. Increased use of custom chip solutions for specific channel readout systems.
Small size, high performance, low power per function and radiation hardness are key parameters. Advances in commercially available small quantity chip production pace the possibilities. One can anticipate that on-detector systems will continue to track the most advanced technologies available. In addition, specialized technologies are being invented by physicists, particularly in the area of pixel detectors of various kinds and sensitivities that will challenge mechanical and thermal designs.

2. Increased use in industry of high-speed serial and wireless links.
Fiber, radiation resistant fiber, high speed serial copper and wireless technologies, driven by the commercial computer interconnect segment, offer exciting new capabilities for detectors as well as controls electronics as speeds and bandwidths increase. Whereas in the past we have concentrated modules into crates with a common controller to reduce per-module support slots, which is not a particularly attractive architecture for controls functions that may be many meters or kilometers apart, we can now visualize small boards interconnected serially with no backplane support at all except for a bulk power connector. At the same time the architecture still works well for close assemblages of serial I/O modules plugged into a mainframe or rack mounted chassis.

3. Development of extremely high density, high power logic chips.
New deep sub micron feature size chip technologies have spawned new chips with hundreds of pins and high power consumption at voltages as low as 1.5 volts. This technology will find applications in both detector and accelerator instrument systems and demands new packaging and cooling techniques. These include short serial links on-board for interconnects as well as parallel connections, and a range of cooling options to handle the extra heat. Watts per square area will be higher than before. Various liquid cooling schemes are being used in detectors now; a number of these are negative atmospheric pressure systems to prevent fluids leaking into surrounding delicate circuitry or structures.

4. Radiation Protection & Radiation Hard Technologies
Detectors are designed for a 10-20 year lifetime and electronics inside the detector must withstand radiation, typically gamma and neutron doses. Commercial off-the-shelf electronics is preferred but cannot be used without shielding in most situations. Electronics close to the beam must be made with radiation hard technologies because replacement is usually impractical. Components that cannot be made radiation hard, such as large area power chips used in regulators, and large filter capacitors, often limit the proximity with which electronics can approach the source of radiation (i.e. beam or interaction point). Similar issues arise in accelerators, where there are great savings to be had in cable plants if electronics can live in tunnels with little or no radiation shielding. This is not usually the case, and in addition there are always areas of accelerators where even radiation hard electronics cannot survive for long. Nonetheless, there are two approaches to the problem: Bury the electronics behind shielding, and/ or use radiation resistant or radiation hard chip technologies.

Clearly any application of a standard in this milieu will have to be different from our old standards. Although there may always be a need for crates and modules, it is possible that many of the immediate and short term future problems will be solved by commercial standards, such as VME, with or without embellishments aimed at the physics user community.

Interestingly, one facet of a future standard intended to serve as a package for some of the systems just described is being explored currently by VITA[4], the VME Industry Trade Association. This group of manufacturers is spearheading an effort to define new strategies for standard modules. This effort could impact future designs not only of detectors but other accelerator instrumentation as well. Some of the features being considered include a flexible standardized form factor and mechanics, Eurocard dimension-based; data transfer by high-speed serial copper, fiber or wireless; various cooling options including liquid; higher power capacity than even FASTBUS to accommodate new low voltage high power density digital chips; and a single bulk power voltage (e.g. 48V) that is converted on-board to supply needed voltages to both analog and digital circuits.

This effort resonates with recent work underway on future accelerator instrumentation and control concepts at SLAC for the Next Linear Collider (NLC). Here we are considering systems that emphasize small low power custom chip instruments that can live in protected holes in tunnel walls, or live in open areas without protection if built of radiation hard components. It appears that VITA, operating with significant input from pioneers of CAMAC and FASTBUS, may produce a standard that is attractive for accelerator control and for larger areas of future detector designs than the current standard modules.

The VITA effort begs the question of whether there is still an impetus for standards in the laboratory communities and suggests evaluating anew whether we can foresee promising areas for standards. We should also try to imagine the roles that laboratories can and should play in future standardization efforts, whether commercial or inter-laboratory in origin, or a synthesis of both.

5. WHAT ARE SOME POSSIBLE FUTURE AREAS FOR MODULAR ELECTRONICS STANDARDS?

The following list is not the product of serious deliberations but merely suggestions worth discussing. The motivation is to create standard design teams that will share the fruits of designs among laboratories and within laboratories, to minimize engineering effort spent on packaging, cooling, connector and power designs and decisions, and to develop a body

[4] Private communication, R. Downing of University of Illinois (ret.) is a consultant to Fermilab. Downing designed the first FASTBUS crate, backplane and cooling system while at SLAC that was produced commercially for evaluation by collaborating laboratories. He is currently Chairman of the VME Standards Organization (VSO) and has brought many of the FASTBUS ideas into the discussion of a standard for advanced chip technologies.

of systems expertise among the laboratories that can speed up the design cycle and minimize cost and effort in configuring large new systems. We consider here packages that are suitable for buried detector systems as well as beamline instrumentation for accelerators.

VITA New Development form factor: This form factor is flexible so could be used for highly integrated solutions inside of detectors as well as in accelerator instrumentation along beamlines where channel density per meter of length may be orders of magnitude lower.

Daughtercards for VITA form factor: Certain components can expect to change with time, either due to problems in design or manufacturer's change in a product line. Programmable chip manufacturers are notorious for making changes that obsolete existing parts and make them unsupportable. A standard I/O format daughtercard could mitigate such impacts.

Standard hybrid or chip-on-chip packaging format: Could we design a standard micro-module package that amounts to a "module-on-a-hybrid"? Parking stations for custom chips, analog and digital, serviced by standard power pins, on-board serial I/O chips and cooling systems may reduce current crates of applications modules to a flat wafer-like design.

Combined analog-digital chips and arrays: The capability exists now through bipolar-CMOS and features can be expected to improve and stabilize in future. Can we produce sets of specifications for front-end designs that will serve well into the future? Strategies for optimizing yields and being able to replace a faulty micro-channel are important.

Communications: The emerging serial standards for short-haul copper running Gigabit transfer speeds are a natural for internal communications in densely packed detectors. Copper is radiation hard while fibers, which are much more affected but can run farther and faster, can service areas a distance removed from the detector interaction point or accelerator beamline. Long fibers in accelerator tunnels would have to be protected for the long runs but could rely on replaceable short jumpers for final connections. Commercial protocols may have to be augmented by robust error detection and correction codes to provide the necessary reliability in these applications. Alternately a high degree of redundancy often exists in detector designs to soften the impacts of this problem.

Diagnostics and Testing Systems: Engineers spend enormous amounts of time deciding what diagnostics to build into their chips and systems, and designing testers. This seems like an ideal area for engineering collaboration among laboratories. Certain preferred techniques could be gleaned from actual work and made part of a requirements document for certain types of systems. Similarly designs for testing systems could benefit by standard hybrid or micro-board level form factors. Commercial solutions may well exist or can be developed.

Radiation Resistant/Hard Electronics: Chip technologies are growing very slowly in this area. The most promising development is the discovery of radiation hard characteristics of deep sub-micron standard processing technologies that are now available to laboratories at reasonable cost. Since designs are difficult and costly this appears to be a particularly fruitful area for an engineering collaboration and possible identification of standard approaches.

Engineering Collaboration: Although there are many similar efforts underway in detector electronics e.g. in LHC, the engineering community does not seem motivated to collaborate beyond their own particular problem areas. Even within a single detector team there appears to be much wasted motion and effort due to separation of the teams and into isolated entities. Whether standards emerge or not, engineers in these design teams should recognize the value of collaborating to identify the best design tools and techniques for particular designs, and work to promulgate these among other designers.

Engineering for Cost Effectiveness in Chip Design: Engineering Collaboration will help with another chronic issue, that of the lack of a critical mass of business for the chip vendor to make efficient use of his foundry production line, resulting in inability to offer the most favorable pricing to the customers. Furthermore, if teams collaborated across laboratories they could mutually benefit from critical review of designs as a service to one another, e.g. by exchange of design packages and video-conferencing, resulting in a much higher chance for initial success in the fabrication stage.

6. SUMMARY AND CONCLUSION[5]

We have attempted to draw out some possible examples where future standardization may be possible. We have also included in the list some other factors, such as engineering collaboration across laboratory and group boundaries to help achieve a higher level of design integrity, attention to best engineering practices, and a sharing of good design philosophy completely through to the diagnostics and maintenance issues of large system electronics design.

We also imply that the basic motivations for standardization are still valid, even though the technologies and the rate of change have changed dramatically over the years. The engineering principles that govern building for large machines and detectors with twenty year or longer lifetimes, as well as requirements for interchangeability and ease of reconfiguration for much shorter-lived smaller systems, both require a disciplined approach that aims at cost effectiveness of both material and especially human resources.

Whether actual standards as we have known them in the past arise from these suggestions will depend mostly on the motivation of the engineering community that supports these efforts, not on the opportunities. Furthermore the engineering community that lives

[5] Appended are copies of the overheads from the author's October 20, 2000 NIM/ESONE meeting presentation.

primarily in a physics environment needs to demonstrate the cost effectiveness of collaboration and standardization even in fast-flowing technological change, and needs to achieve the required funding to support the continuing standards dialog and associated R&D efforts. It would as much of an error to abandon these efforts to industry, which does not find physics to be a particularly attractive market, as it would be to try to invent standards and standard approaches without reference to the need for industry to be a pro-active part of the process.

The opportunity exists both to invent standard solutions at the chip, hybrid and board level, as well as to benefit from the collaboration in a much higher quality and efficiency of design even if standards are found to have limitations compared with expectations of the past. The current standards bodies should examine their future roles in this light. In their examinations they should add a new instrument, namely a microscope.

Finally, it is important to note that the modular instrument standards efforts of the NIM committee sponsored through various incarnations of what is now the U.S. Department of Energy have made a truly remarkable contribution to the scientific instrumentation field. The ideas were borne out of the needs of a customer base within small and large laboratories and successful standards required both a strong technical and a very strong marketing effort, much of it in the teeth of hostile opposition. There is now a much stronger industrial base of modular instruments on a number of new platforms such as VXI, IBMPC, PCI and others, in part due to the successful demonstrations of NIM, CAMAC and FASTBUS. The impressive longevity of these physics standards settles all arguments of whether the efforts were warranted; as well as calls for a continuation of the collaborative efforts to develop the next generation of laboratory instrument standards and best engineering practices that have proven so successful in the past.

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I thank Louis Costrell, National Institute of Standards Technology, Gaithersburg MD, and Robert Downing of the University of Illinois (ret.), Consultant to Fermi National Laboratory and Chairman of the VME Standards Organization (VSO), for their generous help in recalling history, predicting future trends and critiquing the manuscript. Costrell is the founder and Chairman of the NIM Committee under the U.S. Department of Energy, Office of Science, Division of High Energy Physics. I also recognize literally hundreds of colleagues from the worldwide engineering and physics community, pioneers from both laboratories and industry who have volunteered their efforts over three decades to make possible the successful developments described here. Many of their names can be found listed in the published standards.

REFERENCES

All of the Standards mentioned in this brief overview are available through NIST via L. Costrell, NIST, 245/C229, Radiation Physics, Gaithersburg MD 20899.

APPENDIX

Slide Presentation from NIN/ESONE Meeting, October 20, 2000, Lyon France.

Electronics Instrumentation Standards

Past, Present and… Future?

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Discussion for NIM/ESONE Meeting

NSS 2000 Lyon, France October 20,2000

Summary of Major Developments

- NIM –60s
- CAMAC – 70s
- FASTBUS – 80s
- VMEp – 90s
- ?? – 00s

What Motivated Standards?

- NIM:
  - Lab and commercial products incompatible electrically & mechanically.
  - Led to dependence on single vendors – or none.
  - Standard logic levels, mechanics, connectors & crate saved enormous engineering effort in every lab.
  - Interchangeable vendor products gave user powerful choices and economic advantages.
  - First adopted by nuclear physics (low energy) community, later by High Energy Physics for fast logic.

What Motivated Standards?

- CAMAC:
  - Standard module for data collection, crate and computer interface bus for specialized data collection eliminated enormous custom engineering & associated costs at each lab.
  - Standard software protocols simplified software design, promoted vendor interchangeability.
  - Needed standard controllers for parallel and long distance serial links, platform for microprocessors for intelligent modules.
  - Early users: Accelerator control, telescopes, HEP data acquisition.

What Motivated Standards?

- FASTBUS:
- HEP Users demanded more bandwidth, larger card size to capitalize on dense memory chips and faster micros.
- Embellishments for software configurability, diagnostics & control.
- Special protocols for sparse data and fast block transfers.
- CAMAC data bus "not modern" – FASTBUS went to bidirectional computer bus architecture.

What Motivated Standards?

- VMEp:
  - VME was only commercial data bus with large number of vendors and large non-lab market.
  - Standards group worked to make physics embellishments to fast VME architecture, such as larger connectors, shielding, better backplanes & power distribution.
  - Fueled by some specific lab demand – small.
  - Stopgap measure?

Standards Developments Driven by Technologies

- Transistors:
  - NIM was enabled by high quality fast switching Si (vs. Ge) transistors: Higher logic levels & higher fanout.
- Microprocessors & Memory
  - CAMAC was enabled by advent of microprocessors, integrated circuits for bus I/O and new memory chips.
  - Modular architecture and backplane data bus were enabled by multilayer board technology.

Standards Developments Driven by Technologies

- Computer Architecture & Faster, Denser Components:
  - FASTBUS was enabled by a major increase in speed of micros and in density of memories that foreshadowed intelligent modules as the norm for future data acquisition.
  - VMEp was an adaptation by industry of many FASTBUS features to help address the physics market, with some additional improvements.

The Past Role of Standards Committees & Agencies

- Committees helped cast initial concepts into proposed designs.
- Industry co-opted at early stages to collaborate & build prototypes.
- Committees marketed ideas through documentation, experiments, seminars, short courses, conference reports, real applications.
- Connection with National Bureau of Standards (NIST), ESONE, IEC, IEEE, ANSI were key to rapid approval of standards.

The Past Role of Standards Committees & Agencies

- Committees successfully articulated economic and technical advantages to funding agencies and received strong development support.
- Economic and engineering payoff a major success.
- *In retrospect, the high success of standards essentially invented, marketed to supporting agencies and transferred to an industrial base by the small physics research community has been a remarkable achievement!*

The Turbulent 90's: New Technological Challenges

- Initial uses for standards focused on experiments.
- In the mid 80s custom chip and hybrid technologies became available to the labs.
- Opportunity to eliminate huge front end cable plants, racks, crates, auxiliary building space if custom channel electronics placed *inside* detectors.
- New packaging schemes tailored to interstices of plumbing, magnets, calorimeter iron etc.
- No standards!

Example: The SLD

- Major impact on detectors demonstrated by SLD (SLAC Large Detector) which mounted all electronics but a dozen crates of pre-processing electronics *inside* the detector.
- Enormous cost reductions achieved in front ends.
- Enormous racks /space reductions.
- More hermetic detector due to minimal holes needed for cables.
- Use of FASTBUS crates confined to high end data collection and pre-processing, second level trigger etc.

Enabling Technologies of 90s

- Custom chip design, simulation tools.
- Small foundries for protoypes; MOSIS.
- Highly complex Multilayer design tools.
- Hybrid circuit design tools.
- Fiber optics –analog transmission as well as digital pioneered to get data out of detectors.
- Maturation of FASTBUS for top end systems.

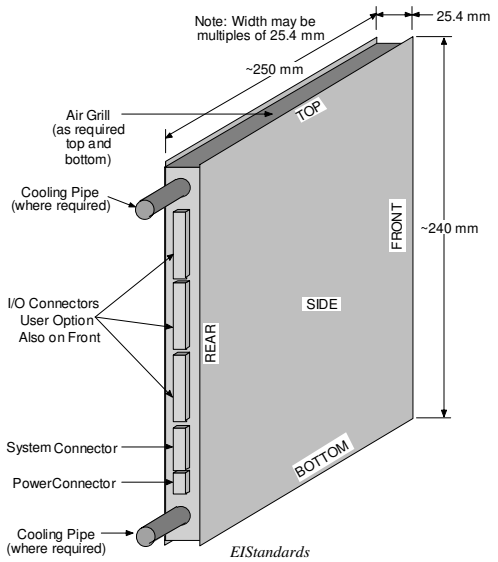
Looking Ahead

- Enabling Commercial Technologies Today:
  - High speed Gb/s fiber & copper serial data links.
  - Wireless data links emerging.
  - Manifold higher densities for micros, memories standard commercial parts.
  - Very low voltage chips @ very high currents..
  - Hundreds of pin packages.
  - Very low cost custom chips in *standard* commercial processes (incl. radiation tolerant)
  - Higher cost Radiation / hard chips in Bi/CMOS commercial processes

The VSO (VITA) Initiative

- VME Standards Organization (VSO) new concept for a standard module of the future:
  - No wide parallel data buses in crates.
  - Backplanes used for power distribution, serial I/O, special functions.
  - Serial I/O options: Copper to 2.5 Gb/s, Fiber to 4.5 Gb/s (today).
  - Slower buses for crate control.
  - Air or fluid cooling options.
  - One bulk voltage (high) converted internally.
  - Eurocard dimensions, with optional form factors.

The VSO Concept



New Accelerators

- New form factor of great interest to not only Detector but Accelerator community for Beam instrumentation & control (e.g. NLC).
- Proposals exist for non-rad hard (protected) as well as inherently rad-hard “instruments on a chip” in tunnels.
- Motivation: Eliminate costly cable plants, racks, power, space.
- Top end controls systems foreseen as entirely commercial computer switching, micro farms etc.
- Networks including picosecond timing/ rf on fiber optic links up to 15 km long.

Future Standards?

- Macro Areas where standards may be possible:
  - Basic instrument card á là VSO initiative.
  - Fiber and copper data links, connectors.
  - Interfaces to VME, PCI etc.
  - Backplane-less crates & fluid/air cooling schemes.
  - Error detection/correction software in controls at front end data gathering nodes.
  - Controls software system architectures.

Future Standards?

- Micro Areas where standards may be possible:
  - Standard functions & pinouts for some classes of custom DA chips.
  - Micro board or hybrid platforms for above.
  - Power busing & conversion schemes for above.
  - Fluid cooling schemes for micro packages.
  - Redundancy & protection circuits.
  - Chip level calibration & diagnostics circuits.
  - Testers & software for all the above.

Why Bother?

- Engineering costs are still a major cost driver in all projects.
- Collaboration to achieve "best practices" knowledge from current experiences has large economic benefit.
- Current engineering investment in custom chip designs is enormous and growing.
- Collaboration *AND* standards equally important for future.

NIM/ESONE

- Combine as a Collaboration dedicated to advancing engineering art in standards for physics.
- Work to leverage current lab investments into future economic and technological gains.
- Form alliances with industry and track state-of-art developments.
- Collaborate internationally on electronics R&D in emerging technology applications.
- Seek modest agency and/or lab funding to sustain long range R&D/ standardization efforts.