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LOW POWER CAMAC AND NIM MODULAR SYSTEMS FOR SPACEFLIGHT USE ON SHUTTLE AND SPACELAB MISSIONS

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Summary

The advent of the Shuttle launch vehicle and Spacelab have resulted in adequate weight and volume such that experiment electronics can be implemented at relatively low cost using spaceflight versions of CAMAC and NIM modules. Studies of 10 modules by manufacturers have shown that power reduction overall by a factor of ∿ 3 can be accomplished. This is adequate both from the point of view of consumption and temperature rise in vacuum. Our studies have shown that a stock of ∿ 45 module types is required and a listing is given. The changes required in these modules in order to produce spaceflight versions are described. And finally, the further studies, prototyping and testing leading to eventual flight qualification are described.

Introduction

The availability of the Space Shuttle as a low-cost transportation system beginning in the late 1970's will result in significant changes in the manner in which the research and applications programs are carried out in space. The Space Shuttle will be used in what is called the sortie mode, earth-orbital missions of ∿ 7 days to begin with, as well as to deploy and possibly recover orbiting satellites and space probes. Often the Shuttle orbital vehicle will carry in its cargo bay a science support system called Spacelab. The modular Spacelab system generally consists of a man-rated, pressurized module, as well as several pallet sections as described in a previous paper.[1]

Spacelab is being designed and built by the European Space Agency (ESA) and its contractors in cooperation with the National Aeronautics and Space Administration. Spacelab will provide a comfortable laboratory environment for experiments and for experimenter(s) when necessary. Most missions which do fly the Spacelab will probably include one or more pallet sections. Experiment sensor systems and often the entire experiment will be mounted on these pallets and will be directly exposed to space when the orbiter bay doors are open. Many missions will not require the pressurized Spacelab and will use the pallet-only mode of Spacelab. In the latter case, an igloo attached to the pallet provides a pressurized, thermally-controlled environment for the Shuttle interface equipment, Spacelab computers and possibly a small amount of experimenter hardware. The pallets provide standardized power, electronic, mechanical and thermal interfaces. Ordinarily the CAMAC and NIM instrumentation that I'm discussing would be mounted in stacks of several crates directly on the pallet floor.

Sortie Mode

The sortie mode uses the Shuttle to carry experiment payloads together with payload specialist and experiments into Earth orbit for periods from 7 to 30 days. Generally, the experiments will remain attached to the orbiter or pallets, although large sensors such as telescopes may be deployed through the bay doors while acquiring data in orbit. The payload specialists who would accompany some payloads into orbit could be scientists or engineers with a minimum of spaceflight training.

This sortie mode is envisioned to operate under a philosophy similar to that developed over the years for the scientific, engineering and applications investigations carried out in the various NASA airborne and sounding rocket programs. It is envisioned that entire payloads consisting of a Spacelab in its various configurations and/or satellites to be deployed would be delivered in an integrated and tested assembly to the launch site for a typical Shuttle mission configuration.

Modularization and Standardization

It is clear that the availability of a relatively low-cost reusable launcher for large payloads, Shuttle, will result in quite a different approach to the manner of carrying out investigations. On conventional spacecraft weight, power and volume have often been major constraints leading to customized, demanding designs which may only be used once. The changing and improving parts technology in the past decade has driven this effect. This has been costly both in terms of money and demands on the available, experienced manpower. This situation has led to an especially demanding reliability and quality assurance program. The Shuttle's system will allow weight, power and volume constraints to be relaxed. This will not only allow the launching of heavy payloads consisting of either large groups of small experiments or of several large experiments, but will inevitably lead to the standardization and modularization of electronic and mechanical assemblies in the experiment hardware, as well as the Spacelab, Shuttle orbiter and launch vehicle themselves. Such standardization and modularization is not only cost effective, but obviously enhances the system's ease of design, repair and modification and allows the reuse inherent in the overall Shuttle concept.

To many of the readers of this paper, the potential for the use of CAMAC and NIM standard, modular electronic systems is obvious. These instrumentation systems were developed originally to serve the needs of nuclear research institutions in Europe and North America. They have the advantage of extensive, proven user acceptance and experience. We will endeavor to show you their usefulness in the Shuttle program and to acquaint you with the development and study programs which are now underway.

CAMAC and NIM Studies for Shuttle/Spacelab

Consideration of CAMAC and NIM is included in several studies at the systems level by NASA and ESA groups and their contractors. ESA, for instance, presently has a contract with the Austrian Society for Atomic Energy and its subcontractors for the study for the use of CAMAC in the Spacelab.

A study directed by the NASA/Johnson Space Center and carried out by the Aerospace Systems Division of Bendix Corporation addressed to the applicability of CAMAC and NIM to various payloads being considered by ESA and NASA.[2] Table 1 summarizes a major result of that study, showing applicability of standard, available CAMAC and NIM modules to the six experimental payloads chosen for the study. It is at once obvious that CAMAC has wide applicability within the experiments

TABLE 1: APPROXIMATE PERCENTAGE OF PAYLOAD ELECTRONICS FEASIBLE FOR NIM/CAMAC

Payload	% of Digital in CAMAC	% of Analog in NIM
Astronomical Observatory	80	5
Atmospheric Science Facility	90	0
Auroral and Magnetospheric	90	40
Cosmic Ray Laboratory	100	90
13-Band Multispectral Scanner	30	0
Orbital Microwave Radar	90	0

considered. Most portions of the experiments dealing with moderate-speed digital data acquisition and control and analog data collection and distribution can be implemented with existing commercially-available CAMAC modules. Only the very high data rate experiments such as the multispectral scanner and video systems in general do not lend themselves to CAMAC implementation.

The NIM instrumentation has more limited usage as one might expect, since it is geared toward pulse handling applications. It is very useful for investigations in high-energy astrophysics including X-ray astronomy, gamma-ray astronomy and the cosmic-ray experiments. Its limited usefulness for auroral and magnetospheric experiments noted in the Bendix study would be greatly increased by the availability of a few new modules. It is apparent to many of us who are daily concerned with the design of instrumentation for space experiments that the NIM standard[3] is ideal for low-level analog circuitry, and the mechanical system is rugged and readily available. It makes good sense to us to design and package most linear circuitry, threshold discriminators and logic circuits beyond the detector preamplifiers and high-voltage bias supplies according to the NIM standard.

The study by the Aerospace Systems Division of Bendix and a further study by TRW Systems Group[4] for the Johnson Space Center anticipate using the CAMAC and NIM instrumentation within the pressurized, controlled environment of Spacelab. Since this volume and atmosphere are used by the astronauts as well, heavy demands are placed on the CAMAC and NIM in terms of safety, materials, outgassing and human factors. These, in turn, will have a substantial impact on cost.

At the Goddard Space Flight Center, several Shuttle studies have been underway, including one especially concerned with aiding the High Energy Astrophysics Management Operations Working Group. This group of experimentalists studying X-ray and gamma-ray astronomy, cosmic-ray physics and high-energy nuclear physics, can implement their experiment electronics almost entirely with existing CAMAC and NIM instrumentation. It should be noted that sensor preamps and power conditioning are not included in the CAMAC/NIM equipment since they usually must be located directly at the detectors due either to special sensitivities or problems of high voltage distribution in vacuum. With the publicity growing out of this work, we are now briefing and teaching experimenters concerned with astronomy, solar physics, the atmosphere, ionosphere, magnetosphere, etc., particularly with the advantages of such a space-qualified CAMAC system.

GSFC CAMAC and NIM Studies

The group of astrophysics experiments considered in this GSFC study are typically very complicated, requiring large weight, volume and power. They are so sophisticated that several will be best implemented by the inclusion of a microprocessor. These experiments usually are totally automated and do not require experimenters in space with them, and thus they are adequately provided for in a Spacelab pallet-only mode. This mode maximizes the weight and power available to the experiments by eliminating the substantial burden of the large pressurized compartment.

On the other hand, the CAMAC and NIM equipment proposed is not adversely affected by vacuum operations. Several NASA groups have been routinely using them as parts of electronics systems for experiments on high-altitude balloons. There are potential problems in some modules due to high power dissipation in particular components - leading to hot spots and thermal problems. Another power problem results from the need of many of the astrophysical experiments for 21- to 30-day missions vs. 7-day missions in order to gather necessary statistics. At present CAMAC and NIM power levels the Shuttle fuel cell assigned for the experiments is not adequate for the longer missions. Putting on an additional cell would require the removal of one or more of the 4 to 5 experiments in question. Both of these problems can be solved with CAMAC and NIM designed for lower power operation. Often in CAMAC this can be accomplished simply by using components which require less power and perhaps cost a little more or are just becoming available, e.g., low-power Schottky T^2L vs. standard T^2L logic circuits. It is clear that in the highly-competitive CAMAC and NIM commercial markets cost must be low, and there is little constraint on power. We will have to take a somewhat different position, paying a higher price to get lower power consumption.

In our work with experimenters we have defined more than 40 modules which would have substantial usage. These modules are listed in Tables 2 and 3.

Presently we have concluded studies by three manufacturers of CAMAC and NIM modules concerning 10 of their modules - 8 CAMAC and 2 NIM modules. A study by a fourth manufacturer is just underway concerning three of his modules, as well as special studies of the flight qualification of his hybrid circuitry. We asked them to study power reduction, component changes, packaging for the vibration loads, and estimating ultimate costs vs. quantity, including appropriate reliability and documentation.

Results of the first three studies showed that there are no serious parts or fabrication problems for these modules. NASA-approved parts are readily available in place of most of the commercial parts. Education and some training are required in NASA fabrication methods, layout and soldering. Design for the vibration environment seems straightforward. Power reduction by a factor of ~ 3 seems attainable for the CAMAC and NIM modules with a typical experiment. Some CAMAC modules show power reduction by a factor of 5 to 10. The smallest power reduction was shown for a spectroscopy amplifier where only a $\sim 25\%$ reduction was possible unless performance parameters were changed - e.g., ± 5 volts out vs. ± 10 volts out. Often these power reductions came about by incorporating a more expensive, or more modern component such as Schottky T^2L integrated circuits.

TABLE 2: NIM MODULES FOR SPACEFLIGHT USE

AMPLIFIERS

Spectroscopy Amplifier
Quad Gen. Purpose Amplifier
Quad Fast Linear Amplifier
Dual Fast Linear Amplifier, Var. Gain
Biased Amplifier

LINEAR FAN-INS

Quad 2-Input/Dual 4-Input Fan-In
Dual 8-Input/16-Input Fan-In
Dual Expandable Summer

LINEAR FAN-OUTS

Dual 8- or 16-Bit Fan-Out

DELAY AMPLIFIER

Step Selectable Delays

THRESHOLD DISCRIMINATORS

Quad Fast Discriminator
Constant Fraction Discriminator
Integral Discriminator

LOGIC MODULES

MECL Logic Module
Quad Gate and Delay Module
Quad and/or for Fast NIM Levels

BINS, CRATES, MODULES, ETC.

Crates and 1/2 Crates
Bins and 1/2 Bins
DC-DC Converters for Crates and Bins
Kluge Modules

TABLE 3: CAMAC MODULES FOR SPACEFLIGHT USE

CONTROLLERS

Controller with Microprocessor
Type U with Computer
Type L Serial Controller with Associated Driver

SCALERS

4/24-Bit 150 MHz
Hex TTL/NIM 50 MHz
12/24 Bit 0.5 MHz
2/16 Bit Preset Scalers
4/16 Bit Presettable Up/Down

SPECIAL PURPOSE DIGITAL DATA

RAU Interface for Commands and Data
8K Words x 24-Bit RAM Module
256 Words x 24 Bits, First in/First Out Buffer

D/A CONVERTERS

8/10-Bit DAC
2/12-Bit Fast DAC

POSITION ENCODERS/DRIVERS

Dual Incremental Position Encoder
Dual Stepper Motor Driver
Motor Driver

OUTPUT REGISTERS

12-Bit Output Storing Registers
2/24-Bit TTL Output Registers

INPUT REGISTERS

12/Bit NIM Fast Latch
2/24-Bit TTL Input Register
2/24-Bit TTL Input Gate

A/D CONVERTERS

8192 Channel Pulse ADC
12/1024 Channel Charge Digitizer
2/12-Bit Successive Approx. ADC
Quad Time Digitizers
15-Bit ADC (Short-Term Stability)

ANALOG DATA MODULES

32-Channel ADC/MUX
32-Channel MUX Expander

CLOCKS/TIMERS

Real-Time, Presettable Clock
Dual Timer Module

Even with these power reductions, the full requirements of IEEE Standard 583[5] are being met. Large power reductions resulted from incorporating ± 15 volts and + 5 volts as standard, bussed voltages.

The substantial reduction in power consumption eases the job of thermal design of the modules and module/crate/bin system considerably. Various mechanical changes are being made and will be discussed presently, but it appears that the maximum temperature rise within a module may be held to ∿ 25°C. For most modules it more typically will be 10 or 15°C.

Currently proposals are being solicited competitively for the redesign and prototype fabrication of a spaceflight version of a CAMAC crate, a NIM bin and power supplies (dc-dc converters) for each.

We anticipated also a similar contract for a CAMAC controller with microprocessor. The available commercial modules have been found not to be good candidates for redesign and derating for spaceflight use. The decision has been made for the GSFC Instrumentation Branch to design these particular modules.

As a result of this work, it is now clear that an adequate supply of modules, crates, bins and power supplies will be available by mid 1977 to carry out a meaningful sequence of demonstrations and environmental qualification tests. These tests then would provide one of the major inputs to a NASA decision for the implementation of our Shuttle/Spacelab experiments with such space-qualified CAMAC and NIM modules.

Mechanical Modifications

Several mechanical changes have been made to the CAMAC and NIM modules to enhance their performance under vibration and to enhance their ability to conduct heat. The basic mechanical standards are still being met, however; and so a commercial module may be inserted in a spaceflight bin or crate, and it will fit, receive the proper power and see the proper electrical interface. Most changes are concerned with CAMAC modules, and these will be discussed as the example.

Fig. 1 outlines a CAMAC module. While the commercial module has only a lower screw lock assembly on the front, the spaceflight version provides for three: one each on the front upper and lower and one on the rear just above the edge connector. These provide additional mechanical support as well as better guaranteed thermal paths. The figure also shows that the standard Lemo connectors have been replaced by screw-type, 50 ohm connectors (Sealectro SRM series), and locking-type toggle switches. Not shown for clarity on this drawing are the side shields which will be required on both module surfaces. Substantial formed aluminum shields add considerable thermal conductivity and mechanical strength to the module. A number of aluminum standoffs are attached between the shields and the boards on both sides. Additionally, the crates and bins are specified to have module edge slots which are mechanically driven or spring loaded so as to guarantee good thermal connection between modules and crates or bins.

Figure 2 shows a line drawing of a side view of a spaceflight crate with a rear-mounted dc-dc converter as the power supply. In the general case, these crates will be stacked two or three units high on the pallet. The crates provide for bolting themselves together in such a stackup. The stacking/shunt bracket shown enables the stacking but also provides a convenient heat path for the heat originating in the dc-dc converters. The crate specifications call for substantial use of thick aluminum to provide the required conductance through and around the crate.

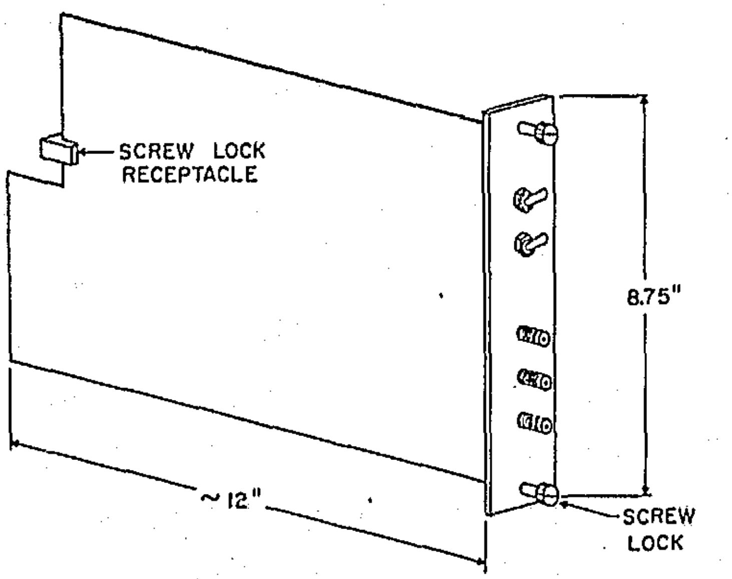

FIG. 1: CAMAC MODULE

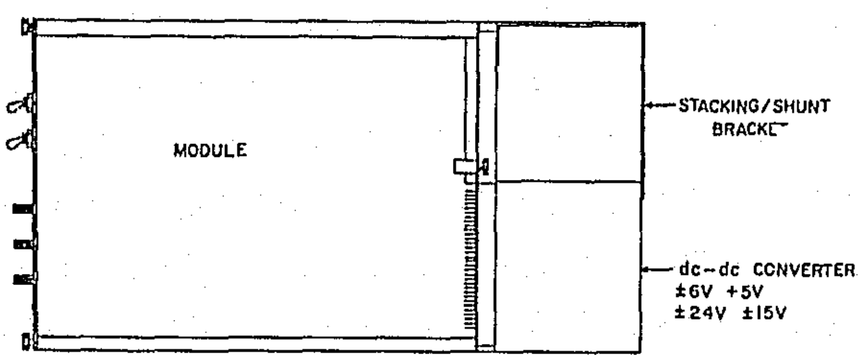

FIG. 2: SIDE VIEW OF SPACEFLIGHT CRATE

Cost Effectiveness

A prime motivation for the use of a standardized, modular system is cost as well as its functional value. We have studied several potential experiments as first examples. These are large experiments weighing from 1200 to 5000 Kg and requiring $\sim$ 200 to 300 watts total power including that for the commercially-available CAMAC and NIM modules. As already discussed, preliminary results from the studies underway by manufacturers show promise of considerable reduction in these power figures. An engineering version of such an experiment could be built using commercial CAMAC and NIM modules for a present cost of from $25,000 to $50,000 for the modular electronics.

We believe that individual modules in the space-qualified version will cost from 2.5 to 8 times as much as the present commercial modules depending upon complexity and the quantity of the buy. Using these figures we would expect the overall CAMAC and NIM system for these astrophysics experiments to cost $\sim$ 6 times more than the commercial system. Using the factor of 6 as the pessimistic approach, and comparing the result with the cost of our lowest cost conventional spaceflight electronics, we predict that the cost of implementing the system with space-qualified CAMAC and NIM will be a factor of 5 to 10 times lower. These calculations did not include any factors as to the reusability of these modules on many experiments; and these will have a large effect, improving the cost-effectiveness even further.

An obvious question is: Why is this approach so much cheap than our previous lowest-cost space electronics? There are several reasons:

1. The modules, especially the CAMAC modules described by IEEE 583, are quite functional and useful to the experiments, and therefore there is a need for reasonable quantities of these modules. Assuming a mission mix of two sortie missions per year with payloads devoted to research in astronomy, solar physics and high-energy astrophysics, one probably would need a stock of 1300 to 1500 total modules spread over 45 module types. In these quantities the manufacturers are able to show a substantially reduced cost over our usual buy of 2 or 3 units. Key to this conclusion is the requirement for NASA or a contractor to stock these modules as a result of quantity module procurement.

2. The Shuttle system has allowed us to use weight and volume as a trade-off against cost. This is very cost-effective. It is very expensive to build small, light-weight electronics for space use, both in terms of the parts and the design and fabrication.

3. Modules built to IEEE 583 and the NIM standard are well established. The interfaces, both mechanical and electrical, are well understood and proven. Especially in the case of CAMAC, a substantial portion of the electronics design has to do with interfacing with the dataway and thence to the controller, other modules, microprocessor, etc. For spaceflight use the major change here is one of buying a higher reliability part and paying more for it, while there should be little design overhead.

4. Most of the functional modules which are needed already exist. This is especially true for those experiments which fall in the area we refer to as high energy astrophysics, where nearly all modules already exist. Again, the designs are well understood and proven, and very often the translation of a design to a spaceflight version is only the incorporation of better parts.

In addition to the above reasons which lead to lower-cost modules, there is a further major cost benefit of the CAMAC and NIM standards, and which is indeed applicable to all useful standards. One quickly builds an experienced group of users. Overall systems design time is shortened, as are the processes of integration and debugging. A new system can be on-line much faster and at a lower cost therefore. Additionally, these standards provide for modules which can be readily replaced in case of malfunction or need for repair. And finally, both the CAMAC and NIM standards allow one to readily expand one's system.

Conclusions

It appears that both from a costing and functional point of view spaceflight modules built to the CAMAC and NIM standards are very attractive. As discussed, a number of studies are underway and will continue into Fiscal Year 1977, both in industry and at the Goddard Space Flight Center. We need the results of these studies as a further assessment from a different viewpoint. It is clear that this paper is thus a progress report. Not all segments of NASA are convinced that modules built to the CAMAC and NIM standards are the way of the future in space for these experiments, but if applied only to the high energy astrophysics experiments these modules are functionally effective and very cost effective.

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