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A MODULAR, PROGRAMMABLE MEASUREMENT SYSTEM FOR PHYSIOLOGICAL AND SPACEFLIGHT APPLICATIONS

John W. Hines
SENSORS 2000! Program Manager
NASA-Ames Research Center
Mail Stop 213-2
Moffett Field, CA 94035-1000

Robert D. Ricks and Christopher J. Miles
Sensors 2000! Program
Sverdrup Technology-Ames Division
NASA-Ames Research Center

ABSTRACT

The NASA-Ames Sensors 2000! Program has developed a small, compact, modular, programmable, sensor signal conditioning and measurement system, initially targeted for Life Sciences Spaceflight Programs. The system consists of a twelve-slot, multi-layer, distributed function backplane, a digital microcontroller/memory subsystem, conditioned and isolated power supplies, and six application-specific, physiological signal conditioners. Each signal conditioner is capable of being programmed for gains, offsets, calibration and operate modes, and, in some cases, selectable outputs and functional modes. Presently, the system has the capability for measuring ECG, EMG, EEG, Temperature, Respiration, Pressure, Force, and Acceleration parameters, in physiological ranges. The measurement system makes heavy use of surface-mount packaging technology, resulting in plug in modules sized 125x55mm. The complete 12-slot system is contained within a volume of 220x150x70mm. The system's capabilities extend well beyond the specific objectives of NASA's programs. Indeed, the potential commercial uses of the technology are virtually limitless. In addition to applications in medical and biomedical sensing, the system might also be used in process control situations, in clinical or research environments, in general instrumentation systems, factory processing, or any other applications where high quality measurements are required.

SENSORS 2000! PROGRAM

Overview

Sensors 2000! (S2K!) is an Advanced Technology Sensor Systems development initiative based in the NASA-AMES Research Center (ARC) Electronic Systems Branch. The S2K! charter is to research, design, develop, evaluate, and apply biomedical, biosensor, and instrumentation technology for use in NASA Space and Life Sciences Flight programs. The S2K! emphasis applies to all elements of a Sensor System, including transducers, signal conditioners, power and control subsystems, telemetry, packaging, and data systems. To accomplish these objectives, we have implemented a dual strategy, addressing both advanced and enabling sensor technology research, as well as hardware, instrumentation, and systems development, ranging from preliminary engineering breadboards, to ground-based laboratory prototypes, to fully developed, tested, and spaceflight qualified sensor and measurement systems.

Technology Development Emphasis

In keeping with the S2K! strategy outlined above, and recognizing the similarities between sensor and measurement requirements for manifested and planned Life Sciences and Life Support activities, we initially attempted to define and compile discipline specific science measurement parameters, subjects, and test platforms/configurations. The thrust was to converge on a modular, high quality, standardized, hardware architecture which could be applied to multiple scenarios, with the additional capability to be modified, upgraded, programmed, and reconfigured, depending upon the specific requirements and logistics of the application under consideration. Targeted applications and scenarios considered encompassed both research and spaceflight programs.

Research Applications

Research applications included ground-based and near term flight programs, including neurovestibular, cardiovascular, biopotential, musculoskeletal, and life support (water, air quality, and envionmental systems monitoring and control) technology disciplines. Requirements to provide advanced technology biosensors and systems suitable for use in current and planned flight programs involving implantable and external biotelemetry systems over a 5-20 year life cycle have greatly influenced the modular measurement system design.

Spaceflight Program Applications

In addition to the research applications described above, two near-term spaceflight programs have strongly influenced the initial definition of the specific configurations, specifications, and operating parameters of the modular signal conditioning system. These are the US/French Rhesus Research Facility, and the US/Russian Cosmos Biosatellite Program.

The Rhesus Measurement System (RMS) was designed using the modular signal conditioner platform concept to monitor 8-16 channels of physiological data from primate test subjects during an 8-14 day space shuttle mission, planned to be flown aboard the third and fourth dedicated Life Sciences Spacelab missions (SLS-3 and SLS-4). In addition to the primary measurements, the RMS is required to acquire and store digital data during the launch and reentry phases of the flight mission, accept control and command data from the onboard host data management system, and be fully space qualified.

The future requirement to be able to modify, upgrade, or reconfigure the configuration and parameter mix, as well as to double the number of channels from within the same physical space, is a strong justification for the use of a modular, programmable measurement system. Even with the heavy use of surface mount electronics packaging technology, this presents a significant challenge for instrumentation system design.

Bioinstrumentation and sensor systems requirements for the Cosmos '92 Biosatellite mission were even more stringent than those for the Rhesus Project. Logistics of this system required the development of three hybrid integrated circuit function blocks, a manually programmable strain gage signal conditioner card, mode selectable power supply, and an application specific subsystem to measure angular acceleration. An added complication for this system was the requirement to interface and be plug compatible with Russian hardware and signal conditioners, in some cases sharing or splitting responsibilities between functional elements.

Development of modular systems and function blocks for both the Rhesus and Cosmos programs has significantly demonstrated the advantages of using a modular programmable measurement system architecture and approach for Space Life Sciences Instrumentation Development.

MODULAR SIGNAL CONDITIONING SYSTEM

System Configuration(s)

As presently configured, the modular system is configured to accommodate up to 16 channels of input. Physically, it consists of a 12-slot, distributed function backplane, with seven analog signal conditioner slots, two power slots, and three slots allocated for the digital subsystem. Each card measures 125x 55 m (approx. 5 in x 2 in), and is physically contained within a volume of 220x150x70mm (approx. 8.5x6x3 in). Figures 1 - 3 show examples of the backplane and modular cards.

Application specific analog signal conditioner cards have onboard preamplifers, buffers, filter blocks, and programmable gain, offset, and mode selection features. In some cases, preprocessing of the raw analog data is also accomplished. All signal conditioners have onboard calibration circuitry. Although each card is presently application specific, the modular design allows for upgradeability and interchangeability. The signal conditioner design is not limited to biomedical applications, and can be adapted to other measurement requirements with appropriate sensor and logistical considerations.

The microcontroller module uses a Motorola 68HC11 microprocessor and has onboard capability for A/D conversion, parallel digital interface to the signal conditioners, and RS-232 serial communications capabilities. The memory module provides the capability to store up to 3.5 megabytes of 8-bit data storage with battery backup.

In addition to conditioning and level shifting external power (AC or DC), the modular system provides full ground isolation to insure subject safety in biomedical applications. Some power supply configurations which support low noise preamplifiers and signal conditioners use rechargeable batteries to supply the low-noise elements, with a charging circuit activated during periods when data is not being collected. Others operate directly from isolated DC-DC converter power supplies.

Although the primary configuration employs completely self-contained, application specific signal conditioner cards, each having both preamplifiers and output stages onboard a single card, preliminary efforts are underway to separate the preamplifiers from the main amplifiers, and to locate the preamplifers closer to the subject, in an experiment-unique arrangement. This configuration would allow a standard, universal main amplifier block, with application-specific front ends, and may thus reduce the complexity and cost of the signal conditioner module(s), while preserving the specificity of the system. The Cosmos '92 hardware system uses this basic configuration and is being studied for applicability to the overall modular signal conditioner scheme.

General Specifications

For the Rhesus Project, the modular signal conditioner within the RMS is designated the Animal Analog Signal Conditioner (AASC), and is configured as shown in Table 1 for the first (SLS-3) flight mission.

BOARD	INPUT LEVEL (V)	GAIN RANGE	OFFSET RANGE (V)	FILTER RANGE (Hz)
EMG	.1 - 10 mV	400 to 40,000	2.5 nominal	2 to 1000
EEG	.01 - 10 mV	400 to 40,000	2.5 nominal	1 to 100
TEMP	0 - 1 V	0 to 100	2.5 nominal	Low Pass 1 Hz
ECG	1 V P-P	1,2,5,10,20, 50, 100	2.5 nominal	0.05 to 100
Dual RESP	1 V P-P	1,2,5,10,20,50, 100	2.5 nominal	Low Pass 10 Hz
PWR Cond	± 8.5 V	N/A	N/A	N/A
PWR ISO	± 8.5 V	N/A	N/A	N/A
Micro-Controller	68HC11 Microcontroller, provides parallel control ports to cards: 8 ch., 8 bit A/D converter, RS-232 Serial Communications Port			
Micro-Peripheral	Provides control for the memory plus battery backup for memory			
Memory	≥ 2 Mbytes 8 bit SRAM Memory			

Table 1. AASC Board Characteristics.

Module Descriptions

Following is a summary list of some elements, modules, and function blocks currently available or under development. Most have been developed totally inhouse, using the expertise and resources of the Sensors 2000! Program. In some cases, collaborative efforts have been undertaken with commercial sensor/instrumentation/vendors, whereby their technology has been licensed for adaptation and incorporation within the modular signal conditioner architecture. In all cases, a cohesive pathway has been defined, or specified, which can make maximum use of advances in technology, past and current experience, and specific applications,configurations, and logistics concerns.

PRESENTLY AVAILABLE MODULAR SYSTEM ELEMENTS

Backplane

Analog Subsystem(s)

* Electromyogram (EMG) Signal Conditioner
* Universal Strain Gauge Signal Conditioner
* Electroencephalogram (EEG) Signal Conditioner
* Dual Respiration Signal Conditioner

Digital Subsystem(s)

* Microcontroller Module(s)
* Digital Memory Module(s)
* Data Acquisition System

Power Subsystem

* Power Conditioner
* Power Isolator
* Rechargeable Power Supply

Sensors and Interfaces

* ECG/Temperature Biotelemetry Transmitter
* Tendon Force Sensor

Preamplifiers

* Seven Channel Neurovestibular (hybrid)
* Four Channel Neurovestibular (hybrid)
* Four Channel Peripheral (hybrid)

Application-Specific Subsystems

* Biotelemetry Receiver(s)
* Respiration Measurement Systems

PLANNED UPGRADES

Present plans for upgrades and additions to the modular signal conditioning family include further miniaturization and consolidation of existing signal conditioner and function blocks, making further use of surface-mount and hybrid circuit packaging, and semi-custom integrated circuit and multi-chip-module technologies. We intend to further merge the various elements and components into a distributed, integrated system which can be rapidly prototyped and applied to specific applications, including those outside of the primary Space Life Sciences thrust. The family of signal conditioner cards will expand to include other life sciences disciplines including cardiovascular, optical, and biochemical/biological measurements, as well as those parameters particular to environmental, life support, and process control scenarios.

A significant amount of emphasis will be placed on the development, use, and application of implantable and external telemetry systems, in a variety of embodiments, to increase the utility and applicability of the instrumentation in distributed, remote, and unattended situations.

CONCLUSIONS

The modular signal conditioner approach described in this paper represents an effort to consolidate instrumentation and measurement system architectures for Space Life Sciences Sensor Systems. These systems have been and are continually being subjected to rigorous analysis and testing to qualify them for flight on the Space Shuttle and eventually Space Station Freedom. Components have been chosen for the highest reliability and performance standards. Units are built to withstand vibration, thermal variations, ambient pressure fluctuations, and electromagnetic susceptibility, and compatibility. In most cases, the units are designed and built for minimal or unattended operation, in highly critical situations where failure to perform will result in the loss of costly and irreplaceable information.

Although the modular signal measurement system has been developed initially for physiologic measurements onboard Life Sciences Spaceflight missions, the technology lends itself extremely well to any sensor or measurement situation where small, high quality, modular, reconfigurable instruments are needed. Because the device has been developed specifically for spaceflight applications, a great deal of attention has been given to safety, quality and reliability issues. The system lends itself exceptionally well for both general purpose and discipline specific applications.

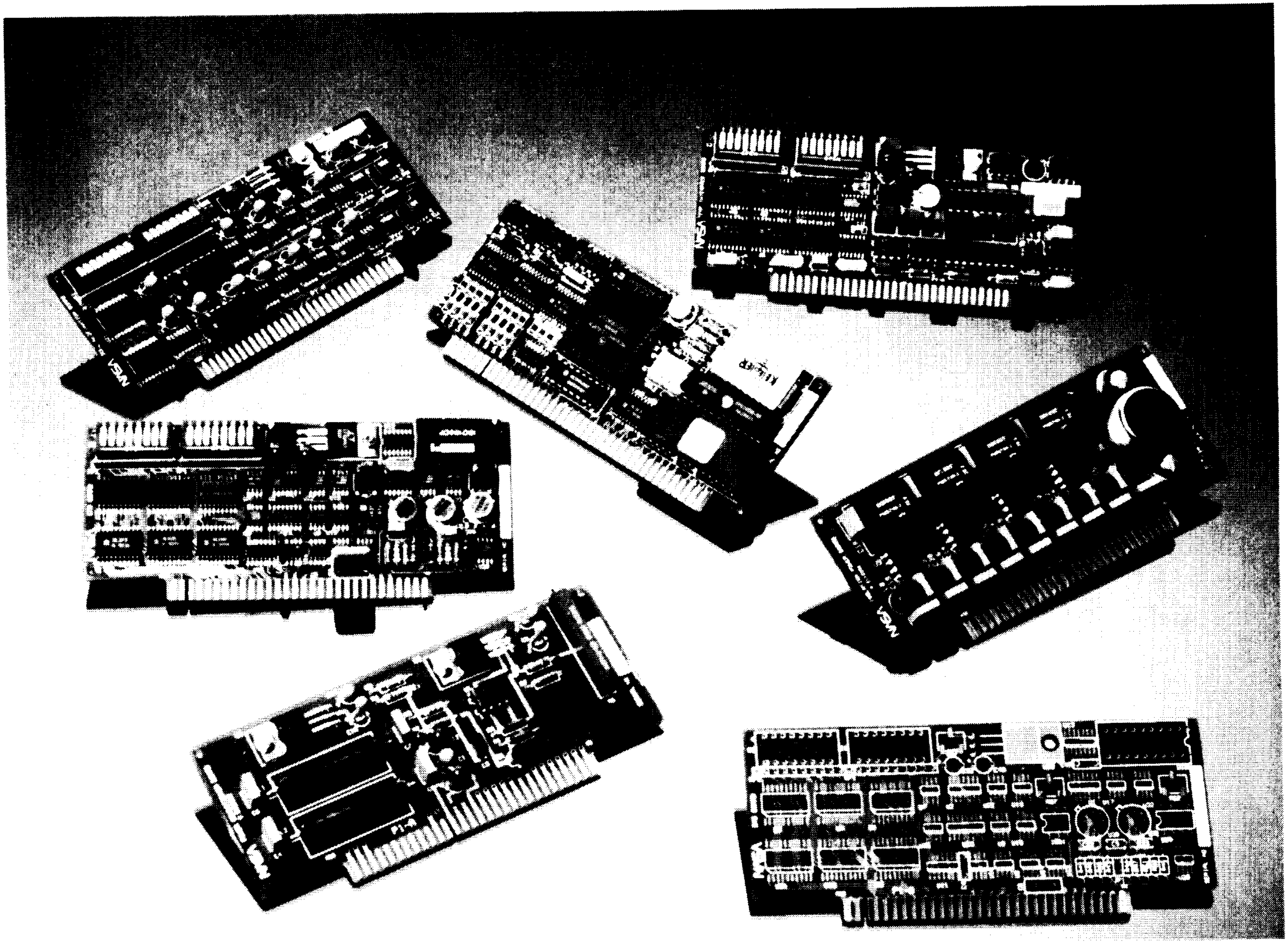

FIGURE 1: Modular Signal Conditioner Card Suite

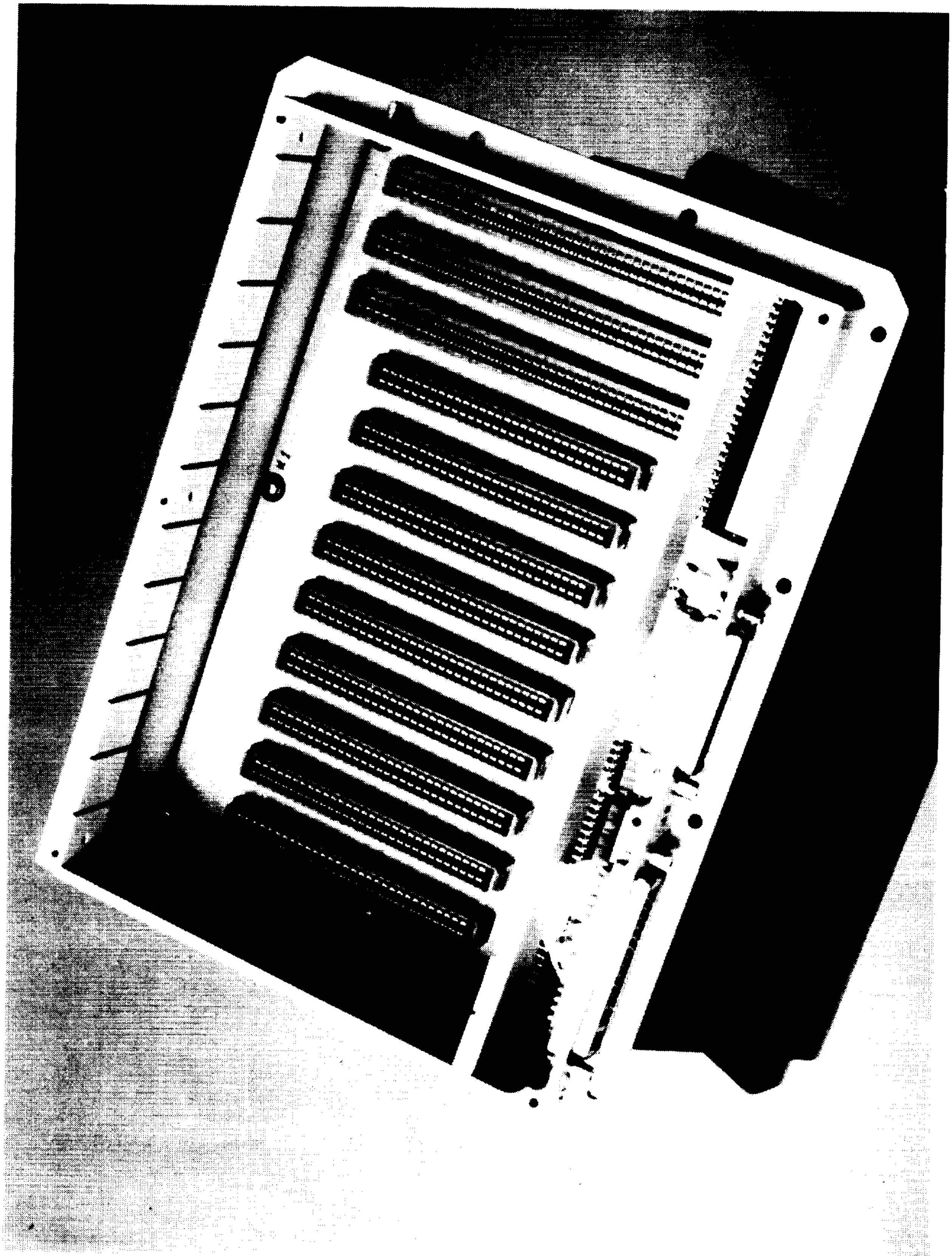

FIGURE 2: Modular Signal Conditioner Backplane

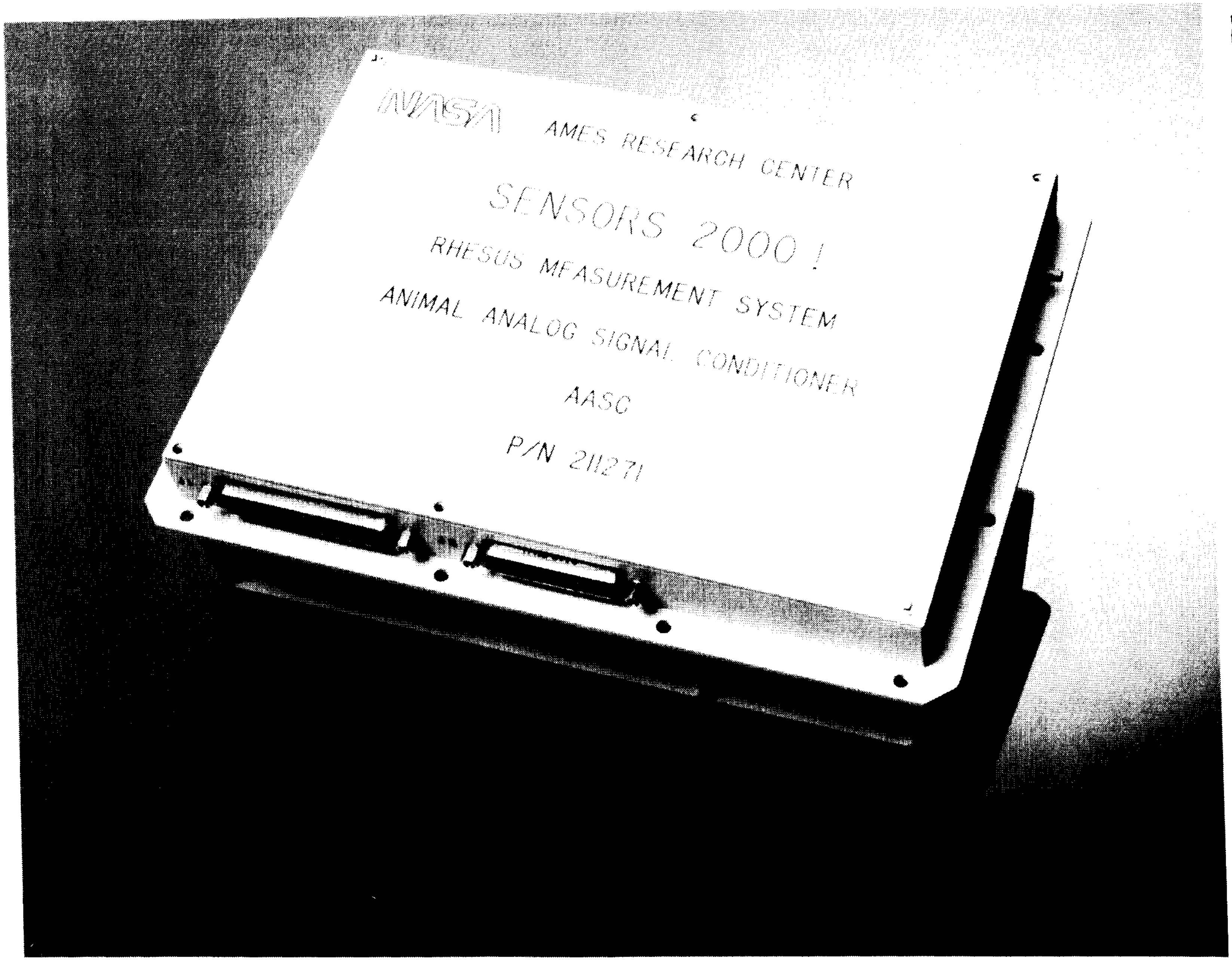

FIGURE 3: Rhesus Measurement System Signal Conditioner