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TEST DATA ACQUISITION SYSTEM FOR THE ESTEC LARGE SOLAR SIMULATOR AT ESA/ESTEC

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ABSTRACT

ESA has placed a contract to Carlo Gavazzi Space for the study of a new data acquisition system for the ESA Large Space Simulator and for the implementation of the prototype. The program has been completed successfully, the prototype tested and its performance demonstrated by ESTEC. The paper describes the device characteristics, its performances and the system aspects connected to the integration into the space simulator instrumentation and environment. The data acquisition system has modular architecture and manifold configuration capability. The input characteristics feature high resolution and accuracy/stability for the measurement of low level (thermocouple originated) analog signals, even in presence of high common mode and S/N figures. The output is serial digital, compatible with ESA data handling standards. The device is designed to be installed in particularly hostile environment, such as that of a solar simulator, and saves in this way large amount of harness and the formerly used slip ring coupling. The implemented prototype is described in details in the paper, which provides also the results of the unit's characterization tests.

INTRODUCTION

To face the increasing demand of testing large systems in space simulating environment, ESTEC has endeavoured enhancement of their 10 metre Dynamic Test Chamber (DTC) to convert it into a Solar Simulator Facility, with a 6 metre diameter beam (LSS = Large Solar Simulator). Large systems under test mean also a large amount of sensor data to be transferred to the Control Centre of the DTC; successful use of the chamber for IRIS and Hipparcos has proved recently that the background concepts are correct and adequate, while the means should be prepared on time to upgrade the data acquisition capability to meet the requirements of such programmes as Columbus and Hermes.

The increased capability however should not cause electrical problems neither at the level of acquisition (e.g. noise, common mode) nor at the level of data transmission to the control room (e.g. number of slip-rings and cable bundles), while reliability shall possibly be improved, along with a simplified maintenance scheme.

The Data Acquisition and Encoding System for thermocouple signals presented in this paper has been successfully tested and designated as candidate for being used in the LSS in the near future.

INFRASTRUCTURE ENVIRONMENT

New instrumentation to upgrade the LSS has to be conceived as an extension to the existing facilities, to satisfy the growth capability of the original system design and to optimize the overall project costs which have to stay in the boundaries of a very tight budget. The structure where the new data acquisition instrumentation has to be integrated has the following main characteristics:

- test articles to be tested are supported by a platform isolated from chamber and building motions

- test types in the same chamber are: dynamic, infrared, vacuum thermal cycles and solar simulation

- test operations, under vacuum conditions, are: deployments, separations, dynamic balancing, spin performance, determination of MOI (Moment of Inertia)

- large infrared test rig and control equipment is available

- the LSS is linked to all other environmental test facilities of ESTEC, namely vibration equipment, optical alignment and checkout equipment, customer's EGSE, acoustic chamber, antenna test (EMC) facility, etc.

- the simulated solar light beam is horizontal and is very stable in time (although not necessarily uniform in space and spectrum)

- the light energy density in the reference plane is 1.6 kW/m.

THE THERMOCOUPLE DATA ACQUISITION DESIGN CONCEPT

The amount of sensors on a sample and the level of thermocouple signals impose the main design drives to the Data Acquisition System:

- modularity and expansibility
- common mode rejection
- noise immunity
- digital processing of signals and data concentration
- digital transmission link, with facility of error correction codes.

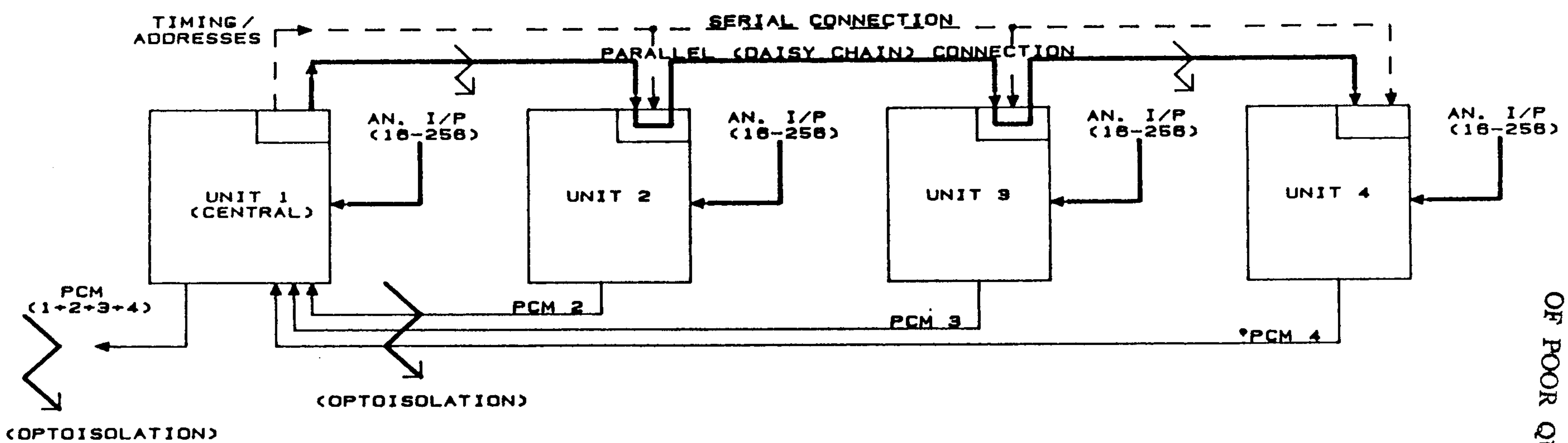
As test samples are often moved during the test with respect to the LSS structures, data have to be fetched from it to the Control Room through slip rings (or radio link) this leading to the requirements of:

- having the maximum number of data on minimum number of output lines
- providing for peripheral collection of data, to be gathered into a central unit
- designing the Data Collection Structure in such a way that it can withstand the same thermal vacuum and environmental conditions as the test sample
- assembling the unit into sturdy compact box, mounted close to the test sample with minimum impact with physical test set up.

Modularity shall be such that more than one autonomous unit can deliver serialized data to a master module (CPU and formatter) for further concentration and serialization, to reduce the number of output lines, therefore of slip-rings, compatibly however with the required sampling rate.

GENERAL CHARACTERISTICS OF THE DATA ACQUISITION UNIT

The unit conceived by Carlo Gavazzi Space to fulfil the above tasks is mainly based on the modular concept and on the facility to electrically decoupling all its interfaces. A sketch of a 4 unit configuration system is in fig. 1.



NOTES : – SERIAL CONNECTION MAY REPLACE PARALLEL LINK FOR DIGITAL TIMING/ADDRESS DATA

– OPTOCOUPLING IS POSSIBLE IN ALL INTERFACES

– EXPANSIBILITY ALLOWS FOR UP TO 1024 CHANNELS ALLOCATED TO 4 TO 64 UNITS. DEPENDING ON THE CHOSEN MODULARITY

Figure 1. Example of System Containing Four Data Acquisition Units (Flexible Capability)

The individual unit is an acquisition device, which conditions and digitally converts low voltage analog data, namely temperatures, which are measured with characteristics of high resolution and accuracy in hostile environment (-30°C through +50°C, 10 EXP-7 torr). It shall be capable of multiplexing up to 256 analog (low level, differential) channels and of issuing the necessary timing and addressing signals to permit synchronization with other identical units and reporting to a master unit. In the same standard unit is housed the 12 bit plus sign (double integration) A/D converter and possibly the programmable PCM formatter, which yields an organized stream of digital bits out of the collected analog data. While the data output is definitely a serial stream, the timing/addressing signals are in parallel form for the normal version used to handle fairly low number of users. Provision is made for serialized organization also for the timing/addressing signals, to minimize the amount of interconnecting wires, depending on the application: in this latter case the serial output of these signals can be used like a bus.

The unit has been designed to handle low level signals (namely from thermocouples) affected by up to $\pm 16V$ common mode which is automatically compensated. It features very high accuracy and linearity of response in the whole range of operating temperature (the actual specifications and verified performances are in the next sections). The modularity in the unit is at level of 16 channels, expansible to 256 by means of 16 identical modules. Four to 16 units can be used simultaneously to collect up to 1024 low level signals which could generate a single PCM stream issued by that unit, which has been selected to contain the final stage of multiplexing and the PCM formatter. The possible architectures of the system have been conceived to cope with signals affected by either identical or different common modes. Namely, every single module has floating power supply, while coupling between modules and with the programmer is by optocouplers, to allow for acquisition of input signal blocks whose common modes differ by more than 250V.

In this way the recurring problem has been solved of having low level signal sources with different common modes, all the way through offering the facility of centralized processing, therefore a single output line carrying the resulting PCM stream.

Current organization of the unit is the following:

- Power Supply, floating and based on either DC/DC converter (28V DC) or AC-DC converter (110V-400 Hz).

- Central Processing Unit, with output timing and address generation and settable to become either central or peripheral in a system.

- Multiplexer (modular 16 or 64), for low level differential input.

- A/D converter (12 bit + sign, double integration).

- Formatter and serial digital output, issuing 12 bit words and synch codes, with selectable frame and subframe length.

- Optoisolated interfaces (serial and parallel, as applicable).

One module per type can be assembled into an autonomous unit, whose acquisition capability ranges from 16 or 64 (one only multiplexer module; 2 channels may be used for autocalibration) to 256 thermocouple channels (4 to 16 multiplexer modules).

Typical system level possible architectures are shown in fig. 2 for the 3 cases of:

- . groups of signal sources with different range and common mode characteristics
- . signal sources with homogeneous characteristics
- . more than 3 groups of signal sources, with peripheral units connected through a bus.

Extra development has been carried out subsequently by Carlo Gavazzi Space to employ the basic unit into all the envisaged configurations and to make units programmability more flexible. Use of several units communicating through a bus has been taken into consideration and the development is currently ready for different types of application and requirements, both commercial and project dedicated.

MAIN IMPROVEMENTS WITH RESPECT TO THE EXISTING SYSTEM

The functional and performance requirements have been met by the successfully qualified prototype, which has proved to be capable of:

- handling bigger amount of low voltage channels (from few hundreds to almost unlimited, but certainly more than one thousand), by expansion of modular connections

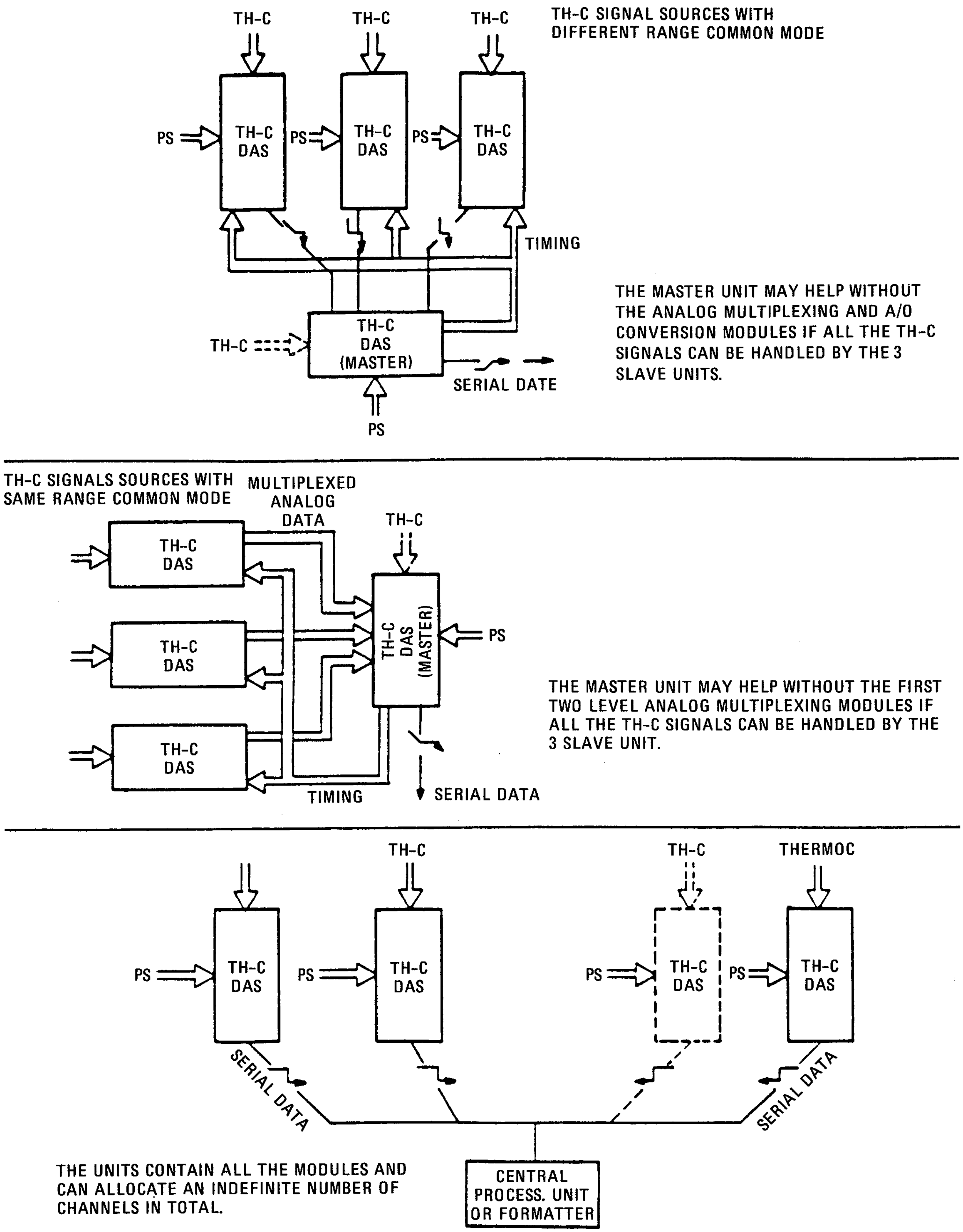


Figure 2. Use of TH-C DAS Unit at System Level

- increasing measurement accuracy, thanks to the built in 12 bit plus sign A/D converter (formerly, the analog data were processed outside the system, in the control centre where they arrived through long length, disturbance sensitive cables)

- tolerating very high common mode levels, without degrading measurement accuracy and noise rejection

- improving electromagnetic interference tolerance, especially on the long cables beyond the slip-rings, thanks to the digital technique used for transmission (formerly, the analog signals running in the cables where seriously affected by the electrical disturbance inducted by the facility service equipment); the digital technique itself may be improved by adding error correction algorithms

- permitting decentralized collection of data, thus:

  . reducing the path of analog signal prior to reaching the nearest collection unit (with improved immunity to noise)
  . optimizing harness length and routing, with improvement of plant cleanliness and accessibility for maintenance
  . improving reliability by multiple levels of multiplexing (a failure in a peripheral unit should not affect more than 16-64 neighbour channels on a single module)
  . decoupling groups of thermocouple signal sources which can be handled homogeneously by the decentralized collection unit; a failure in one group shall not affect any other group of channels
  . easing maintainability, by local interventions in turn on peripheral units and optimization of facility downtime (modularity is such that any peripheral unit might even replace the master unit, if this one fails, thus providing for a set of immediately available spare modules)

- reducing quite drastically the need for slip-ring contacts (only the lines carrying PCM, clock and safety signals have to be transmitted to the steady part of the facility)

- reducing the amount of harness carrying the thermocouple measurement information outside the facility.

Reliability and maintainability improvement deserves further clarification: in fact the new data acquisition unit is conceived to suit architectures with space type characteristics, with the further advantage of immediate accessibility in case of preventive or corrective maintenance.

The selection of components, which shall withstand simulated space environment, makes the unit reliability figure definitely higher than the commercial equipment's used so far. Moreover interchangeability of modules, as already mentioned, permits to replace immediately those units which may have failed in a critical area of the facility. The only critical item is the central multiplexing and formatting unit gathering all data from the peripheral multiplexers: should the need arise, this unit could be made redundant like in the usual space electronics practice.

Along with reliability, maintainability is improved, not only due to the intrinsic lower probability of failure, but also thanks to the new architecture. In the previous facility, in fact, data could only be processed in the control room, a few hundred metres apart, and the operator in the facility could only communicate with the control room by telephone link. Local digital processing of data allows for a central computer terminal to be placed in the facility where the operator gets an immediate replica of the data displayed in the control room. Moreover, by means of a simple telemetry decommutator, the operator himself has straightforward access to anyone of the Data Acquisition Units (either peripheral or central) thanks to their serial digital output; this saves testing time and prevents misinterpretation of data. Especially in those configurations where redundant processing unit is available, maintenance interventions are possible without stopping data processing by the facility, except for only those parts which are maintained.

This aspect of improved maintainability has been stressed because current experience demonstrates that facility down time has critical cost impacts on any affected program and re-organization of the maintenance approach becomes absolutely necessary for cost effectiveness.

Finally, in can be stressed that installation of systems of any complexity is sensibly easier than for the current architecture, with reduction of harness, simplification of documentation, improved flexibility of application, smaller size of equipment and easier access to interfaces.

SUMMARY OF THE UNIT SPECIFICATIONS

General Features

The basic unit functional block diagram is shown in fig. 3. The general features are summarized hereinafter:

- modular 16-64 differential analog input multiplexing (up to 4-16 modules per unit, maximum unit capability 256 channels)

- up to 3 additional units connectable to a central unit performing A/D conversion, serialization and electrical decoupling

- facility for electrically decoupling all interfaces

- more than 100 dbDC and AC (more than 500 Hz) common mode rejection ratio on thermocouple generated signals, in the electrically decoupled architecture

- 12 bit plus sign A/D conversion, double integration, followed by a programmable amplifier with maximum gain of 1000

- high linearity and low gain error (see performance below)

- 12 bit plus sign and overrange parallel digital output

- PCM serial digital output, plus synchronization and timing signals

- parallel digital input (ON/OFF) capability

- facility for autocalibration and for autocompensation in the operational temperature range (-30°C +50°C)

- compact package for aerospace application

- decoupled built-in DC voltage supply distribution

- internal staus monitoring channels (2 in each unit).

Optional Features

On request the following extra options are available on the baseline unit.

- 19 inch crate mounting architecture
- stabilized (protected) DC voltage lines for slave units
- DC power inputs from master unit ($\pm$19V, +12V, +8,5V, -6V)
- programmable size and format of serial PCM (to accommodate all collected channels)
- additional digital or analog inputs and outputs to permit connection of more than 3 units to a master unit
- facility for polling interrogation by a central data processing unit (computer bus protocol interface).

Specifications

Power input	: 20 kHz sinewave 500 mV p/p ($\pm$10%) 28 VDC ($\pm$10%)
Power consumption	: less than 4 W (basic unit)
Input	: $\pm$5 mV differential thermocouple signals (62-254 channels max, optoisolated), impedance higher than 100 MOhm
Digital output	: optically isolated PCM NRZL (TTL compatible)
Connectors (prototype)	: CANNON, type D*
Size (prototype)	: 183x225x157 (h)
Weight (prototype)	: about 2.5 Kg. with power supply transformers
Sampling rate	: programmable, typically 60 sec. for 1000 channels.

SUMMARY OF VERIFIED PERFORMANCE

The figures recorded here below have been measured in conditions of vacuum and in the whole range of temperature, with input signals

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from -5 mV to -5 mV.

Operational temperature on baseplate	: -30°C...+50°C.
Vacuum conditions	: 10 EXP-7 torr.
Input resolution at maximum gain	: ±1.25 microV.
Maximum linearity error	: ±0.2% of full scale = ±11.2 mV full scale, conventionally taken as ±5.6 microV.
System accuracy (as referred to input):	±4 microV in the range 75°K to 425°K, with measurement repetitivity better than 0.1°K.
Standard deviation (±3 sigma)	: ±8.02 microV max.
Gain error	: ±0.04% (±2.3 microV) max.
Offset error	: -1.7 microV max
Thermal drifts	: Offset : 5.8 ppm FS/°C Gain : -19.8 ppm FS/°C Linearity: ±17.5 ppm FS/°C
Common mode rejection ratio (CMRR)	: DC -137 db AC -106 db DCCOMP -124 db
Common mode voltage	: ±250V between channels of different units or with respect to ground. ±16V between channels of the same unit.

TECHNIQUES AND DESIGN APPROACH

The study phase trade-offs have led to choosing the following techniques to meet the project main targets (all other functions not covered under this section have to be considered as satisfactorily met by current state of the art of commercial components application).

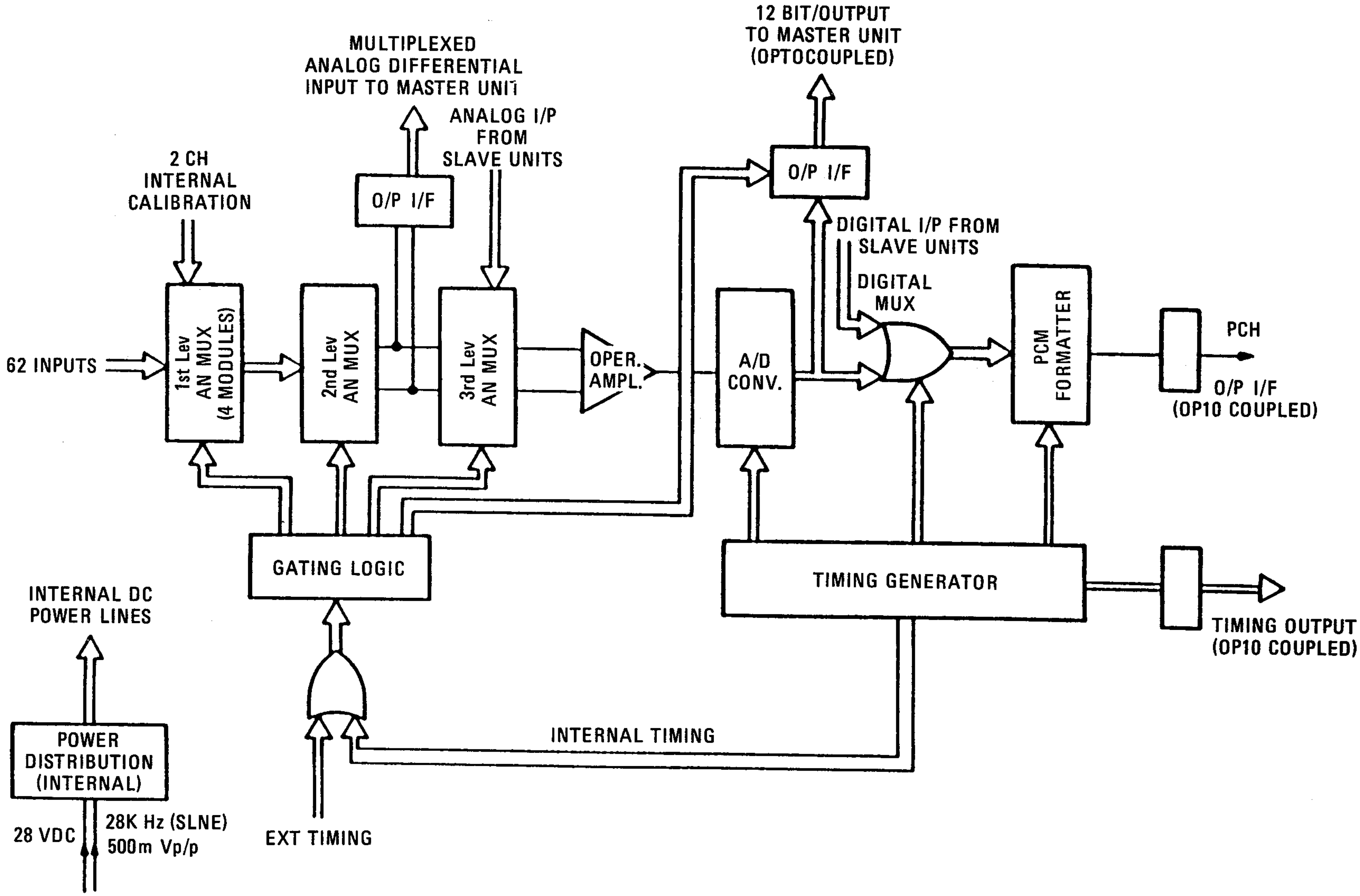


Figure 3. Functional Block Diagram

Effects of set-up errors on gain

Design characteristics are such that set-up errors have systematic effects over the gain, therefore correctable off-line by software. In particular, gain set up is done by means of discrete resistors, thus preventing instability and ageing effects of trimmers.

Causes of gain drifts

The following causes of gain drifts due to temperature sensitive components have been identified:

a) drift of the resistor network defining the differential gain

b) drift of open loop gain of op-amp's

c) drift of over voltage protection resistors and connection resistance (due to non-infinite value of input resistance of instrum.amplifier)

d) drift of ADC reference voltage.

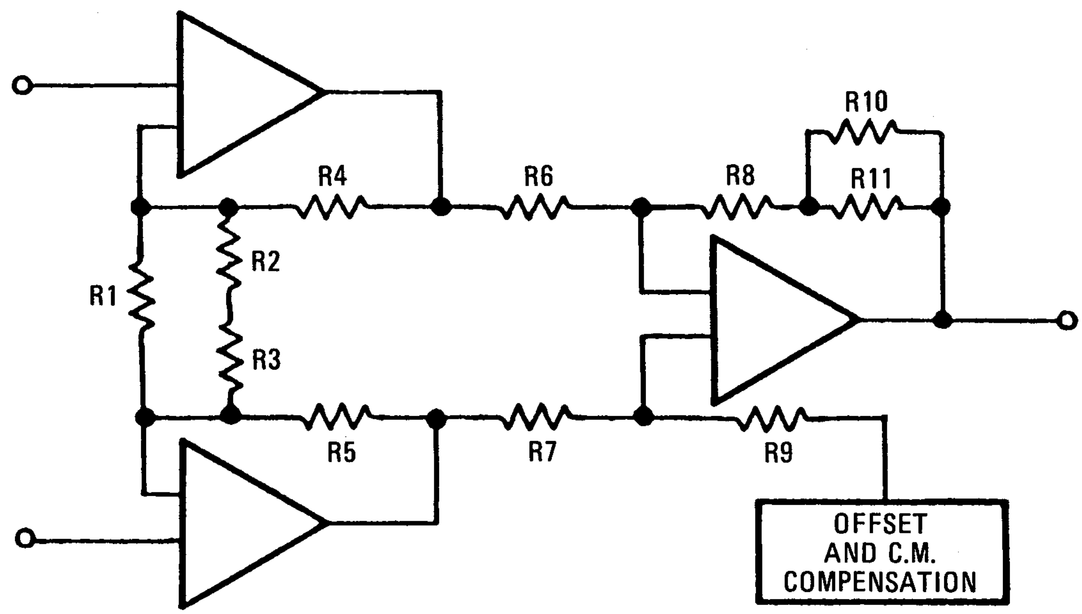
Note that temperature effects on offset are compensated by the selected design techniques. Fig. 4 shows the resistor network layout.

A) Drift of the resistor network defining the differential gain. Overall theoretical drift with 20 ppm/°C resistors with temperature range of 80°C is better than 40 ppm/°C, which can be reduced to about 20 ppm/°C by proper matching of selected resistor value.

B) Effects of open loop gain drift on overall gain. On the assumption that Common Mode Rejection Rate (CMRR) is very high and the signal source impedance is low, a clever selection of the two operational amplifier stages open loop gain leads to a maximum gain drift better than 10 EXP-8 in the temperature range of 80°C.

C) Effects of source and series resistor. On the assumption of instrument amplifier input resistance higher than 2 MOhm and of 2 kOhm total series resistance, the resulting gain drift is better than 10 EXP-4 in the temperature range of 80°C.

D) Effects of Analog to Digital Converter (ADC) voltage reference (VREF). With suitable optimization of VREF stability in the temperature range -50°C to 100°C, the effect on gain drift is better than 10 EXP-3.



- GAIN DRIFT MAINLY AFFECTED BY R_3, R_4 AND R_5 DRIFT DUE TO:
  - FIRST STAGE DIFFERENTIAL GAIN OF ABOUT 10
  - VERY HIGH VALUE OF ADJUSTMENT RESISTORS R_1
  - VERY LOW VALUE OF ADJUSTMENT RESISTORS R_2

Figure 4. Gain Drift due to Drift of Resistor Network

Gain Calibration Approach by Software

The approach consists of mapping into the operator work station the absolute gain error data, observed during a system calibration phase, with respect to the gain calibration performed at ambient temperature during final factory tests; the gain setting accuracy in the calibration phase is 0.2% of full scale. The work station shall therefore correct in real time the received data against the map stored in the system calibration phase (target environment).

The data delivered to the operator are only affected by temperature drift errors, which have been proved to be negligible. Further software correction of temperature effects on gain drift is still possible with the same method, provided the mapping of gain errors in the work station is extended from ambient temperature to a significant number of temperatures in the range -30°C to 50°C; additional information is needed in this case about the actual Acquisition Unit temperature, which needs to be fairly accurate and derived from one of the channels of the acquisition unit itself. Hardware compensation of the thermal gain drift is not recommended due to the insufficient accuracy of the analysed methods. Advantages of software calibration approach are:

- No criticality during initial factory gain calibration phase performed by selection of gain setting resistors.

- No requirements of data acquisition system removal from the target environment (LSS).

- No requirement of hardware modification to data acquisition system.

- Off line preset of calibration data (manual or automatic) and real time gain correction performed automatically in operator workstation, without performing any physical action on data acquisition system.

- Periodic system verification and calibration procedures performed directly by the personnel normally in charge of LSS operations.

Calibration Philosophy

The proposed philosophy is a direct consequence of conclusions of gain error analysis. No action is performed on data acquisition system but its behaviour is analyzed and deviation with respect to theoretical characteristics is recorded for further use during LSS operations, in order to correct actual data from systematic error.

Calibration is performed by personnel normally involved in LSS operations in accordance with a user oriented procedure, with no need for hardware or software specialists. No overhead nor change of current acquisition procedure in the data handling centre:

- data acquisition system correction data are obtained during workstation off line operations
- during LSS operations, temperature data cycles are sent from workstation over HP-IB to data handling centre, on request
- LSS is the master of the data acquisition cycle.

Calibration is performed automatically, therefore reducing possibilities of errors. Calibration is not a time consuming activitty. Calibration is executed:

- on a periodical basis at regular time intervals in order to take control over the accuracy of the system
- on a random basis during the installation of a new spacecraft in LSS or after a corrective maintenance intervention.

Between successive calibrations the operator workstation uses the same calibration data for the correction of the actual samplings from data acquisition system, which are affected by errors determined during calibration phase. Different sets of calibration data can be maintained in the operator workstation, displayed and used during LSS operations under full operator control.

Calibration Procedure for Systematic gain errors

It is executed off line and at ambient temperature. Involved items are:

- a calibration source
- the actual LSS harness
- the thermocouple data acquisition system installed in LSS
- the operator workstation connected to the data acquisition system by the operational links (power and data).

Systematic gain error data are obtained by:

- acquiring data from data acquisition system into operator workstation as during normal LSS operations
- comparing acquired data against the theoretical ones associated to the value of the calibration signal used in the procedure

. determining the correction factor to be used during normal operation in order to eliminate the gain systematic error.

The gain correction factor is stored into the operator workstation and used during normal LSS operations to fetch data already corrected from systematic gain error. The gain correction factor can be displayed by the operator and overwritten if so deemed necessary. The workstation can store a catalogue of gain correction factors, each one associated to a given and well identified (date, S/C...) calibration procedure execution. The operator may use the most recent calibration data or select among the calibration data available in the catalogue.

Grounding and Shielding

Optimum grounding and shielding performance is normally obtained by tailoring to the target system the most suitable philosophy derived from theoretical rules. This design choice however is affected by the uncertainty of several project dedicated requirements, such as:

- thermocouples floating or referred to ground

- location of common mode voltage (CMV) source, whether it is concentrated on the differential low level signal source or distributed over the signal cable (or both)

- EMC environment of the installed thermocouple data acquisition system

- amplitude and frequency of the AC common mode voltage sources concentrated on the L.L. (low level) signals sources

- amplitude and frequency of the noise signal induced in the L.L. signal lines due to the effect of the electric field coupling.

Moreover:

- each thermocouple channel can have in principle AC common mode voltage characteristics different from all the other channels, i.e. the channels, if tightly coupled, can influence each other

- because the acquisition system handles multiple channels with low level multiplexing and centralized signal conditioning, it is not possible to implement a conventional "guarding" approach as on systems with individual signal conditioners and with guard terminals associated to each individual channel.

The selected approach, implemented in the prototype is the following:

- twisted pairs shall carry thermocouple channel signals to affect both lines of a channel by the same coupling

- each twisted pair is protected by individual shield (guard) connected to the low impedance terminal of the low level signal source. This shield, unconnected on the data acquisition system side, closes the loop of the induced AC C.M. currents without affecting the signal lines

- a shield protects a bundle of twisted shielded pairs. This outer shield is connected on one side to the data acquisition system star ground point and on the other side to the system ground via the VTR box structure. Figs. 5., 6., 7., show the preferred grounding concept.

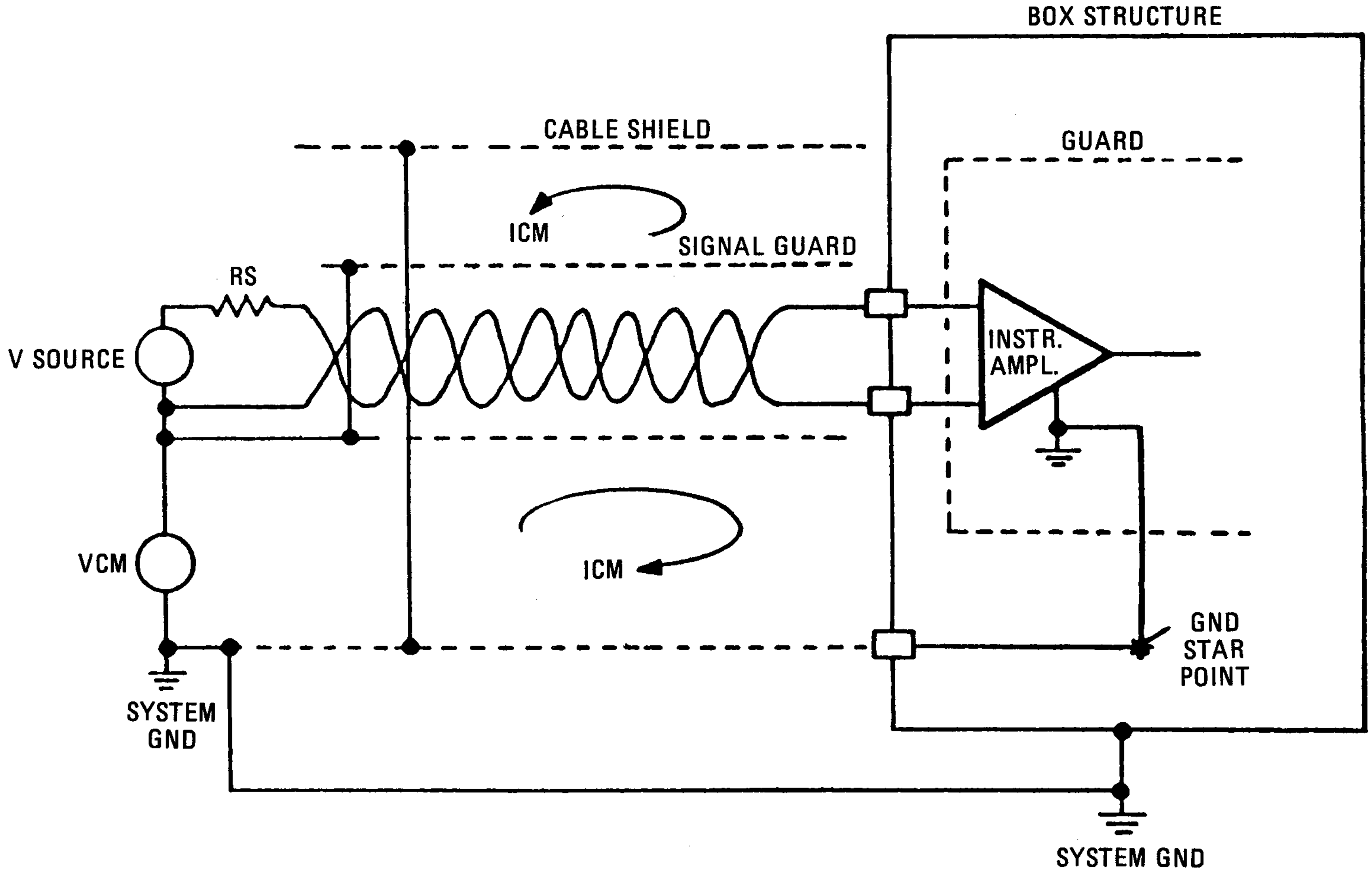


Figure 5. Proposed Ground and Shielding Approach

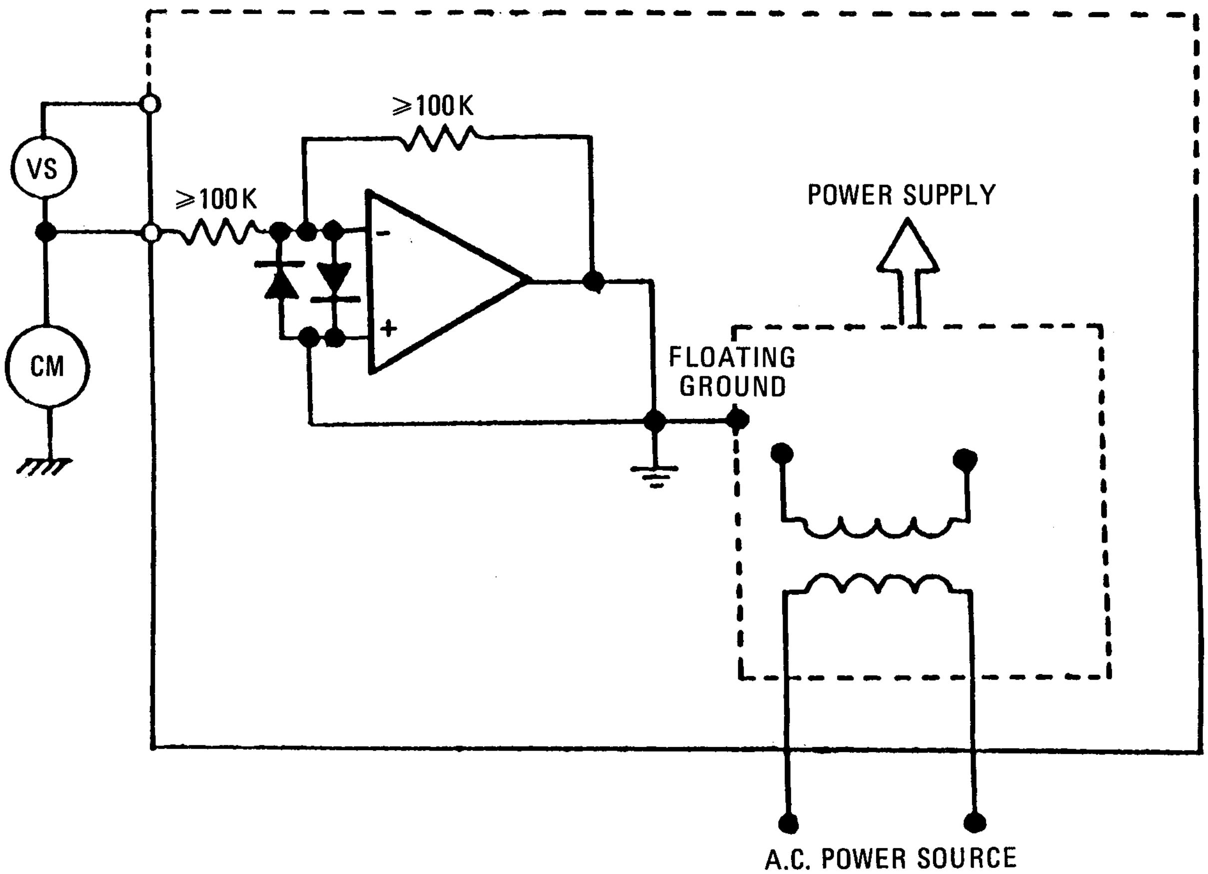


Figure 6. Foating Ground Approach

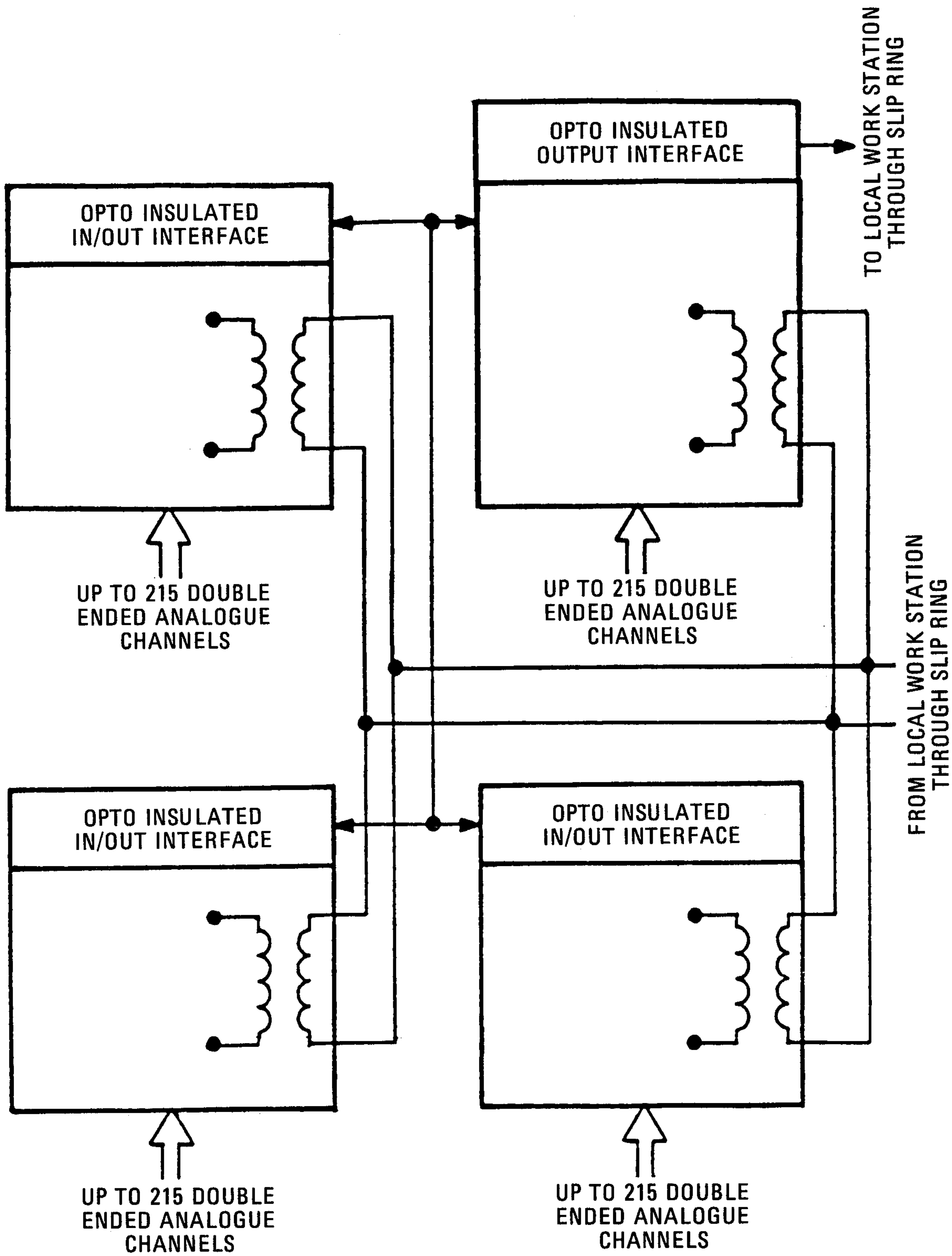


Figure 7. Complete Data Acquisition System Grounding Block Diagram

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16. Abstract

The Institute of Environmental Sciences Fifteenth Space Simulation Conference "Support The Highway to Space Through Testing" provided participants a forum to acquire and exchange information on the State-of-the-Art in space simulation, test technology, thermal simulation and protection, contamination, and techniques of test measurements. The papers presented at this conference and the resulting discussions carried out the conference theme of "Support The Highway to Space Through Testing."

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