A Programmable Data Acquisition System with Integrated Test and Calibration Facilities

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ABSTRACT

In 1985 the new Advanced Technologies Testing Aircraft System ATTAS will be operable at DFVLR Braunschweig. For this research aircraft a flexible, highly accurate and testable data acquisition system was developed. It consists of a modular and distributed microprocessor system with signal conditioning units situated near the sensors. It is controlled by a master unit with an integrated PCM encoder. The flexible signal conditioning featuring software-controlled parameters and adaptable signal inputs, can be tested automatically via the analog calibration bus using switchable signal paths. The system will be presented in detail and its performance will be shown by typical examples of application within ATTAS.

1. INTRODUCTION

The data acquisition system introduced in this paper is used in the new DFVLR In-Flight Simulator, the Advanced Technologies Testing Aircraft System ATTAS. ATTAS (Fig. 1) is a modified VFW 614 aircraft equipped with a computer-controlled Fly-By-Wire System and extensive instrumentation to perform very varied flight tests, particularly for In-Flight-Simulation [1, 2].

In order to capture the aircraft state data during a flight test, the sensor signals from the aircraft must be conditioned and fed to the onboard computer system. In addition, a PCM data stream has to be generated from the sensor signals for telemetry and recording purposes. These form the two main tasks of the data acquisition system, which are explained in more detail in the following.

2. REQUIREMENTS ON THE DATA ACQUISITION SYSTEM

Owing to the broad application spectrum of ATTAS, the varied nature of the flight tests and the high quality requirements on the flight test results, exacting demand are imposed on the data acquisition system [3].

- The signal conditioning must be adaptable to various types of sensors.
- The signal conditioning parameters must be easily and precisely adjustable over a wide range.
- The generation of the PCM frame must be adaptable to the varying requirements of many different users.
- To allow checking of its accuracy, the system must have both static and dynamic test and calibration facilities. It must be possible to include the sensors in the tests.

The DFVLR, in cooperation with HENTSCHEL SYSTEM GMBH [4], has developed a software-controlled data acquisition system with a universal, high-performance structure that meets the above requirements. A detailed description of this is given in the following.

3. STRUCTURE OF THE DATA ACQUISITION SYSTEM

Fig. 2 shows a block diagram of the ATTAS measurement system. It consists of two subsystems, the data acquisition system with signal conditioning and PCM generation in the upper half of the diagram and the test and calibration system in the lower half.

The data acquisition system has a modular and distributed structure; the Signal Conditioning Units (SC Units) in 1/1 ARINC ATR housings are situated near the sensors; in this case in the cockpit and tailplane areas of the aircraft. They are controlled via the Signal Conditioning Control Bus (SSC BUS) by the Signal Conditioning Master Unit, to which they return their digitized data via the PCM BUS. The conditioned data are then passed on in parallel form to the Computer System. Certain signals from the tailplane area initially pass through the Special Signal Conditioning Unit (SSC Unit). In this unit, the signals of those sensors are conditioned which cannot be dealt with by the standardized components in the SC boxes. These are the signals from the base aircraft itself, which have to be galvanically decoupled and/or whose voltage level lies outside the signal level range of the standard signal conditioning.

The Calibration Bus (CAL BUS) forms the external access path to the integrated test and calibration facilities of the data acquisition system. Excitation signals from the test and calibration system can be fed into each SC Unit via this analog bus and system responses can be measured. The control of these measurements is performed in the ATTAS measurement system via the Calibration Control Computer. Owing to its integrated system software, the data acquisition system remains operable with all facilities even without the host computer. In this case a standard CRT terminal may be connected to the Signal Conditioning Unit to allow communication with the user.

3.1. Signal Conditioning Unit

Fig. 3 shows the structure of a SC Unit. In each box there is a section of slots for double sized Euro Card signal conditioning boards, which are connected via a standardized bus structure to the further subsystems of the SC Unit. A maximum of 48 analog sensor signals may be conditioned in one box. Groups of 4 analog signal conditioning channels SC, together with the voltage regulators for the power supply of the connected sensors, are located on one standard analog signal conditioning board. There are further additional conditioning boards for

- parallel and/or serial digital signals in various formats
- ARINC 429 bus signals
- MIL Bus 1553 a/b bus signals
- synchro/resolver/carrier frequency signals.

The conditioned sensor signals are passed internally to the integrated PCM system. Parallel to this, they are also available at the output for further processing in the I/O units of the Fly-By-Wire Computer System.

A part of the SC unit essential to the integrated test- and calibration facilities is the built-in central calibration unit CAL. Within each SC box there is a local version of the CAL BUS which leads to the signal conditioning channels of the SC Unit. Each SC box contains its own microprocessor (central processing unit CPU) which has access via the local control bus to the signal channels SC and the calibration centre CAL.

In order to avoid ground loops in the spatially widely distributed system, the bus interfaces of each SC Unit are galvanically decoupled.

3.1.1. Standard Analog Signal Conditioning Channel

Fig. 4 shows the most important components and signal paths of an analog signal conditioning channel in the form of a functional diagram. The channels are charaterized by

- software-controlled gain adjustable in binary steps from 1 to 1024
- software-controlled offset compensation of sensor output offset with 12 bit resolution
- adaptation to different types of sensors via plug-in modules
- low pass filter cut-off frequency selectable via plug-in module
- overall error smaller than 0.5% FS over the temperature range - 25°C to + 65°C
- versatile integrated test and calibration facilities via switchable signal paths.

Through corresponding layout of the adaption module, a SC channel can be adapted to sensors such as

- potentiometers
- strain-gauge bridges
- thermocouples
- voltage sources

Three different voltages are available to supply the sensors. The adapted sensor signal is conditioned via a programmable instrumentation amplifier and a three-pole Butterworth filter and is buffered at the output. Each channel has a DAC, in order to compensate sensor output dc offset. The relays A, B and C offer multiple facilities for test and calibration of each channel:

- A calibration signal from the LOCAL CAL BUS proceeds via relay A to the input of the conditioning channel. The corresponding ouput signal is passed via relay C to the receive line of the LOCAL CAL BUS. In this way the transfer function of the conditioning channel can be determined.

- The calibration voltage is fed via relay B into the adaptation module. The response received via relay C depends on both the connected sensor and the SC channel. The sensor is included into this test because normally the sensor completes the network of the adaptation module in a bridge configuration.

- As the adaptation module is a purely passive network, the raw sensor signal can be extracted via relay B. The transfer direction on the transmit line of the LOCAL CAL BUS is then reversed.

Fig. 5 shows an analog signal conditioning board with 4 channels. As an example of the lay out of an adaptation module, the adaptation of a 5 kΩ potentiometer sensor to the signal conditioning channel is shown in Fig. 6.

3.1.2. Calibration Centre

An essential part of the Programmable Data Acquistion System is the local, calibration centre corresponding to Fig. 7, which is included in each SC Unit. It features:

- galvanic decoupling of the calibration signal from and to the CAL BUS to avoid ground loops

- attenuation of high level calibration voltages to test high amplification signal channels

- generation of internal calibration voltages in the stand-alone mode of the SC Unit using a 16 bit DAC

- monitoring of housekeeping signals

Fig. 7 shows the block diagram of the local calibration centre. A calibration signal from the CAL BUS is passed via an isolation amplifier to the transmit line of the LOCAL CAL BUS. A precise, programmable attenuator is inserted into this signal path. It is thus possible to generate the necessarily small input voltages for high amplification signal conditioning channels and whilst also sending high level, relatively noise-immune calibration voltages via the CAL BUS running throughout the whole aircraft. The response of the tested SC channel passes via the relay G, the isolation amplifier and the relay H back to the CAL BUS. Before calibration of a SC channel, the calibration signal path itself will be calibrated via the relays E, D, F, G and H. The local calibration centre contains in addition a precise calibration DAC whose output can be used instead of external calibration voltages. Using this, a SC Unit can be tested and calibrated completely in the stand-alone mode. With aid of the housekeeping multiplexer, dedicated internal status information of the SC Unit, such as temperatures, supply and reference voltages and currents can be measured. The overall error of the calibration path in the local calibration centre is less than 0.15% FS over the temperature range from -25°C to +65°C.

3.1.3. PCM Subsystem

Corresponding to Fig. 3 each SC Unit contains an integrated subunit, which can be controlled by the Signal Conditioning Master Unit via the bidirectional PCM BUS. It is used for the following purposes:

- fast and accurate 12 bit digitization of a maximum of 48 analog signals

- formatting of the digital SC input signals, the A/D-converted analog signals and transfer to the PCM BUS.

If a digital SC board is inserted instead of an analog SC board all control and output ports are connected via an address bus and a 16 bit data bus with the optically decoupled PCM BUS interface.

The digitization of the analog data is controlled by the PCM word clock from the Signal Conditioning Master Unit. During the first half of a clock period the analog channel is selected and during the second half the digitized result of the previously selected channel is transferred to the PCM encoder. The use of this "pipelining procedure" avoids unnecessary waiting times. The PCM can work at a maximum rate of 160 kwords/sec with 12 bit resolution.

3.1.4. Central Processor Unit (CPU)

The CPU in each SC Unit fulfils various important tasks:

- communication with the SC master unit via the signal conditioning control bus for command input and status response

- control of parameters and signal paths of the SC channels and the local calibration centre

- self-test

- control in the stand-alone operation mode of the SC Unit

Each SC Unit has a further interface for a standard terminal, whereby the unit can be operated in the laboratory in stand-alone mode.

3.2. Signal Conditioning Master Unit

3.2.1. Signal Conditioning Control

Up to 15 Signal Conditioning Units can be controlled by the Signal Conditioning Master Unit (SCMU) - see Fig. 2. This unit is used for the following tasks:

- control of the signal conditioning and calibration functions in the SC Units
- control of the PCM subsystems in the SC Units and generation of the programmed PCM frame
- quicklook of dedicated PCM-data on the terminal display
- storage of signal conditioning and PCM-system parameters in a non-volatile memory during power off
- self test

In order to fulfil these tasks, all SC Units are connected via two digital bus systems

- the signal conditioning control bus (SSC BUS) and
- the PCM BUS

to the SCMU. The SCC BUS is based on RS-232-C interface standard. With the help of this bus the parameters of the conditioning channels are set within the SC boxes and the diverse test and calibration functions of the system are controlled.

There are basically three different operation modes for the SCMU:

- All functions of the SCMU can be controlled by a host computer - the Calibration Control Computer in Fig. 2, which is connected via a RS-232-C interface. This also includes the transfer of quick-look data to the host computer.
- A standard CRT terminal can be connected to the SCMU via a further RS-232-C interface. This allows the user to access to the different subsystems. The integrated system software allows user-oriented man-machine communication.
- The data acquisition system is operational even without the host computer or a terminal. After power on, the SCMU carries out self tests, loads the SC Units with

parameters from its battery-buffered memory and starts with generating the PCM signal. The loading of SC Units with parameters from the SCMU is repeated as a cyclic process. If the contents of the SC Unit's parameter registers are falsified due to an error then this is corrected automatically by the cyclic refresh.

3.2.2. PCM System

In setting up the PCM frame, the conditioned and digitized analog data together with the digital data are fed from the SC Units via the PCM BUS to the Signal Conditioning Master Unit. In addition, the SCMU can receive bit-parallel word-serial 16 bit digital data from a connected computer via a DMA interface. In ATTAS this connected computer is the Central Communication Computer (Fig. 2) of the Fly-By-Wire System. These data can also be fed into records of the PCM frame, each with a max. size of 256 words.

Fig. 8 shows the PCM frame. Each main frame MF with a maximum len4th of 999 words is starting with a synchronization word. A maximum of 14 subframes can be programmed. Each subframe can be up to 999 words deep. The subframe identifier word ID serves as a subframe count. Fig. 8 shows as an example subframe p located at word n-1. The update word containes the same command as that is passed by the SCMU to the SC Units during the cyclic refresh. This has the advantage that the current values of the signal conditioning channel parameters are embedded in the PCM signal and can be used for control purposes.

The PCM encoder can be programmed very flexibly:

bit rate	1...1.999 $\bullet$ 10^6 bit/sec
word length	8...16 bit
parity, bit format	various possibilities

Each data word slot can be occupied by any analog, digital or DMA word. The word length is individually programmable for each word.

4. SYSTEM SOFTWARE

PROM-stored software is localized in different subsystems of the data acquisition system:

- in the Signal Conditioning Master Unit SCMU, for remote control via the host computer, local control via a CRT terminal and system stand-alone operation.

- in the individual Signal Conditioning Units for SCMU-controlled operation and for the laboratory test stand-alone operation controlled via a terminal.

The programs in the SCMU are 24 kbytes in size and those of the SC Units 4 kbytes.

The user is guided by menus during communication with the system. Numerous editing support simplifies the parameter input. The user has direct access to all test and calibration functions, signal conditioning parameters and PCM parameters via menu expansion into the various application areas. Additional control functions such as automatic zero adjustment of all analog channels or input/output of all stored parameters from/to external storage facilitates operation.

Fig. 9 shows as an example a screen page for control of the analog channels. After the channel number (CHN) in the most left-hand column the computer automatically repeats the position (M/S and WNR) of the channel in the programmed PCM frame. The subsequent two columns allow to input the SC parameters offset (ZERO) and gain (G). The output levels of the channels are displayed on the right-hand half of the screen, using bar graphs. In addition to this graphic presentation, also a decimal indication with 12 bit resolution is selectable, using a special CHECK/MODIFY-Line at the top of the table. With help of this line also the reaction of the selected channel to the input of a calibration voltage can be monitored.

5. APPLICATION OF THE DATA ACQUISITION SYSTEM IN ATTAS

The application of the data acquisition system in ATTAS shows its flexibility and the advantages of its integrated test and calibration facilities. This shall be demonstrated by Fig. 2.

During the certification flight tests, it is used as a simplex system (1 SSC Unit, 2 SC Units, 1 SC Master Unit) without the Test and Calibration System. The operator controls the data acquisition system via the CRT terminal connected to the SC Master Unit. After these tests the sensor configuration changes completely. Because of its flexible structure, the data acquisition system will be adapted to the new configuration in a very short time.

At the beginning of the operation phase of ATTAS as a research aircraft at DFVLR Braunschweig, the Test and Calibration System is integrated and the SSC Unit and SC Units are duplicated. This is part of the redundancy concept of ATTAS with its Fly-By-Wire Duplex System. The data acquisition system is now controlled by the Calibration Control Computer of the Test and Calibration System. This allows the Test and Calibration System to access to various analog and digital signals not only in the data acquisition system, but also in the Fly-By-Wire System. Various automatic test routines are possible:

- calibration of all SC channels. The channel inputs are connected via CAL BUS and relay scanner to the precision digital to analog converter and the channel outputs to the precision digital multimeter. Test results are stored on a floppy disk of the Calibration Control Computer and displayed e.g. as calibration diagrams on the graphic display. This procedure will be incorporated in pre-flight and post-flight checks of ATTAS.

- measuring of dynamic characteristics of the SC channels. For this purpose the Test and Calibration System is expanded e.g. by an IEEE-488 bus controlled Frequency Response Analyzer, which is connected via the relay scanner and the CAL BUS to the selected SC channel.

- dynamic In-Flight Calibration [3] of the Fly-By-Wire System including the electrohydraulic actuators, sensors and signal conditioning. The calibration signal, e.g. from a noise source, is connected via relay scanner, CAL BUS and SC Unit to the tailplane terminal computer of the Fly-By-Wire System, where it is added to the control signal of a dedicated electrohydraulic actuator. The corresponding sensor signal is passed via the SC Unit back to the Test and Calibration System for analysis. Test results may be displayed on the graphic display.

- quick look representation of PCM data on the graphic display, selected via the Calibration Control Computer and on-line analog recording of selected PCM channels using the PCM word selector.

- automatic monitoring of housekeeping data from the SC Units by the Calibration Control Computer.

The components of the Test and Calibration are concentrated at the operator panel (Fig. 10) for the measuring system operator. The touch sensitive display of the Calibration Control Computer, a Fluke 1720 A, eases operation: the operator is guided via menus. Command input is achieved by touching the corresponding menu point (softkey). Setting up the data aquisition system with different SC channel and PCM parameters for different flight test conditions is simplified using floppy disks.

Fig. 11 shows the components of the simplex data acquisition system and the Calibration Control Computer. The components meet the requirements of an operational temperature range from -25°C to +65°C as expected during flight operation.

6. CONCLUSION

The data acquisition system presented here represents a powerful instrument for the ATTAS In-Flight Simulator. Due to its modular structure with distributed intelligent subsystems, its programmability and application flexibility it is a very helpful tool for all measurement and calibration requirements on board of ATTAS. Its integrated test and calibration facilities lead to high reliable and accurate measurement data needed for high quality flight test results.

7. REFERENCES

[1] Dr. Sinclair, S.R.M., “Report by the Chairman of the Flight Mechanics Panel”, AGARD Highlights 83/2, pp. 5-11, NATO, Paris, March 1983.

[2] Dr. Sinclair, S.R.M., et.al., “Future Requirements for Airborne Simulation”, AGARD Advisory Report Nr. 188, NATO, April 1984.

[3] Gandert, R., Karmann, R., “General Integrated Multipurpose Inflight Calibration System”, Paper Nr. 25, AGARD CP-373, NATO, Lisbon, 1984.

[4] “Signalaufbereitungs-Einheit SAE 180” and “PCM-Encoder Datenverwaltungs-Rechner DVR 182”, Technical Manuals of Hentschel System GmbH, Fränkische Strasse 62, D 3000 Hannover, West-Germany, 1984.

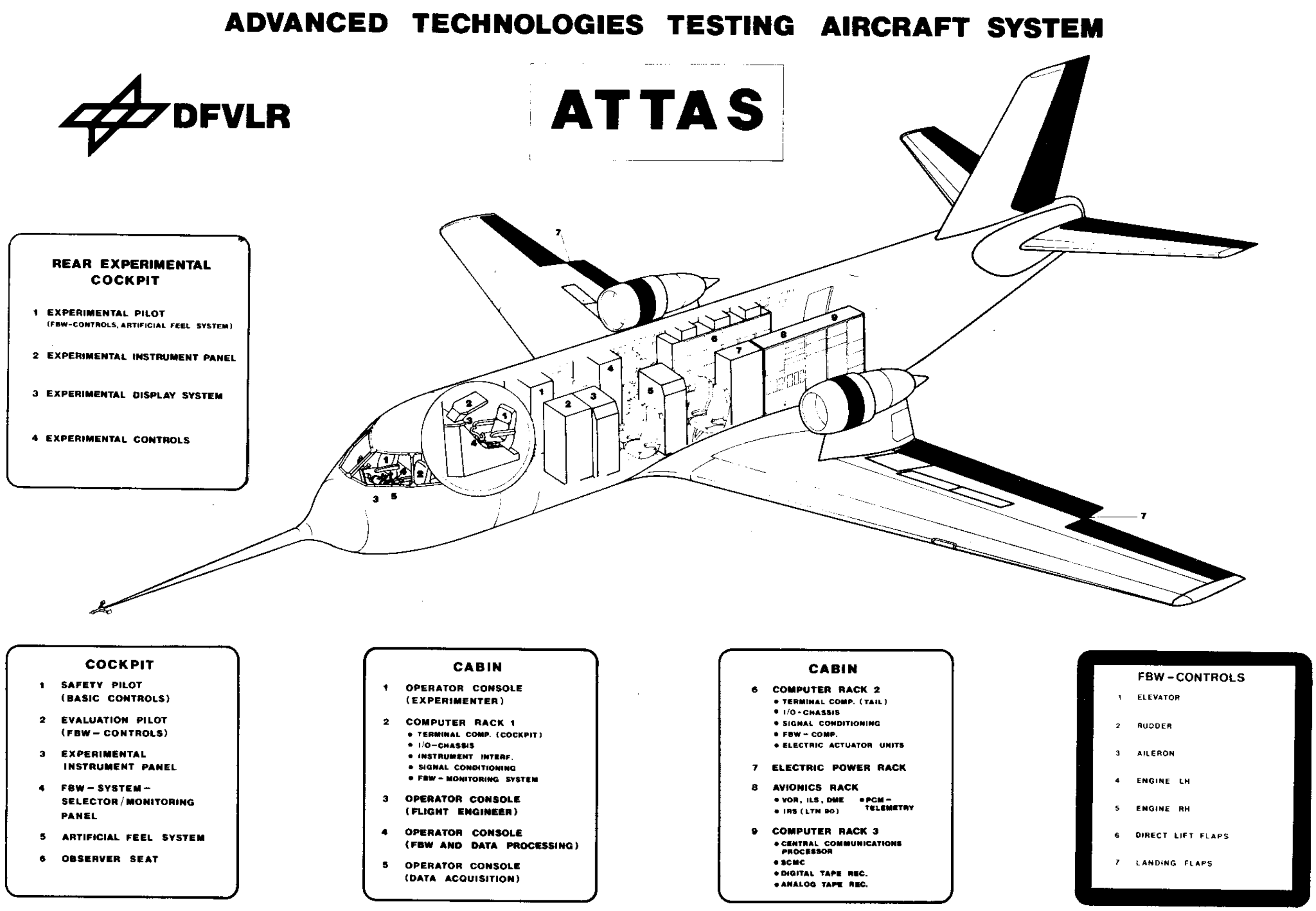

FIG.1 - EXPERIMENTAL AIRCRAFT ATTAS

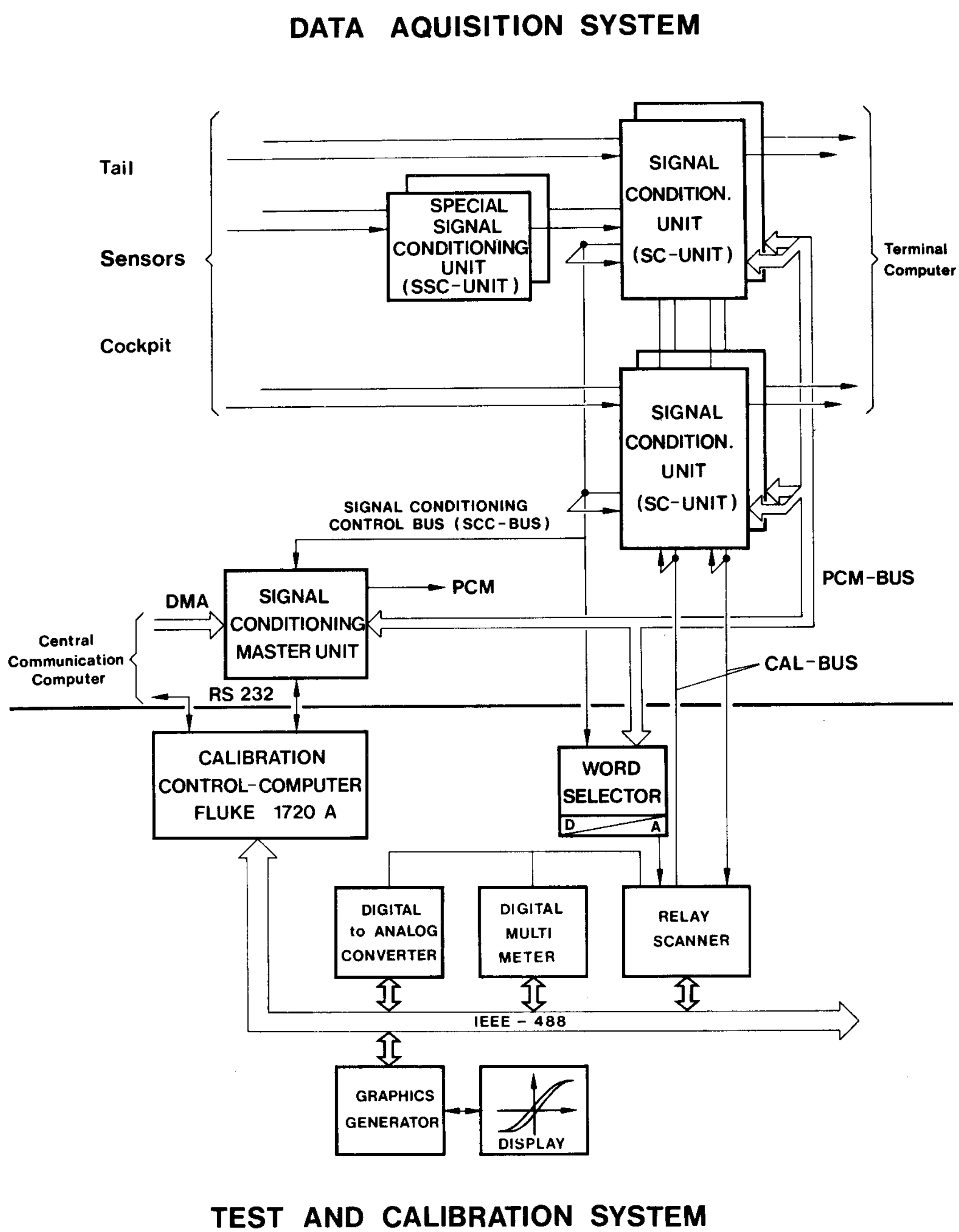

FIG. 2 - ATTAS MEASURING SYSTEM

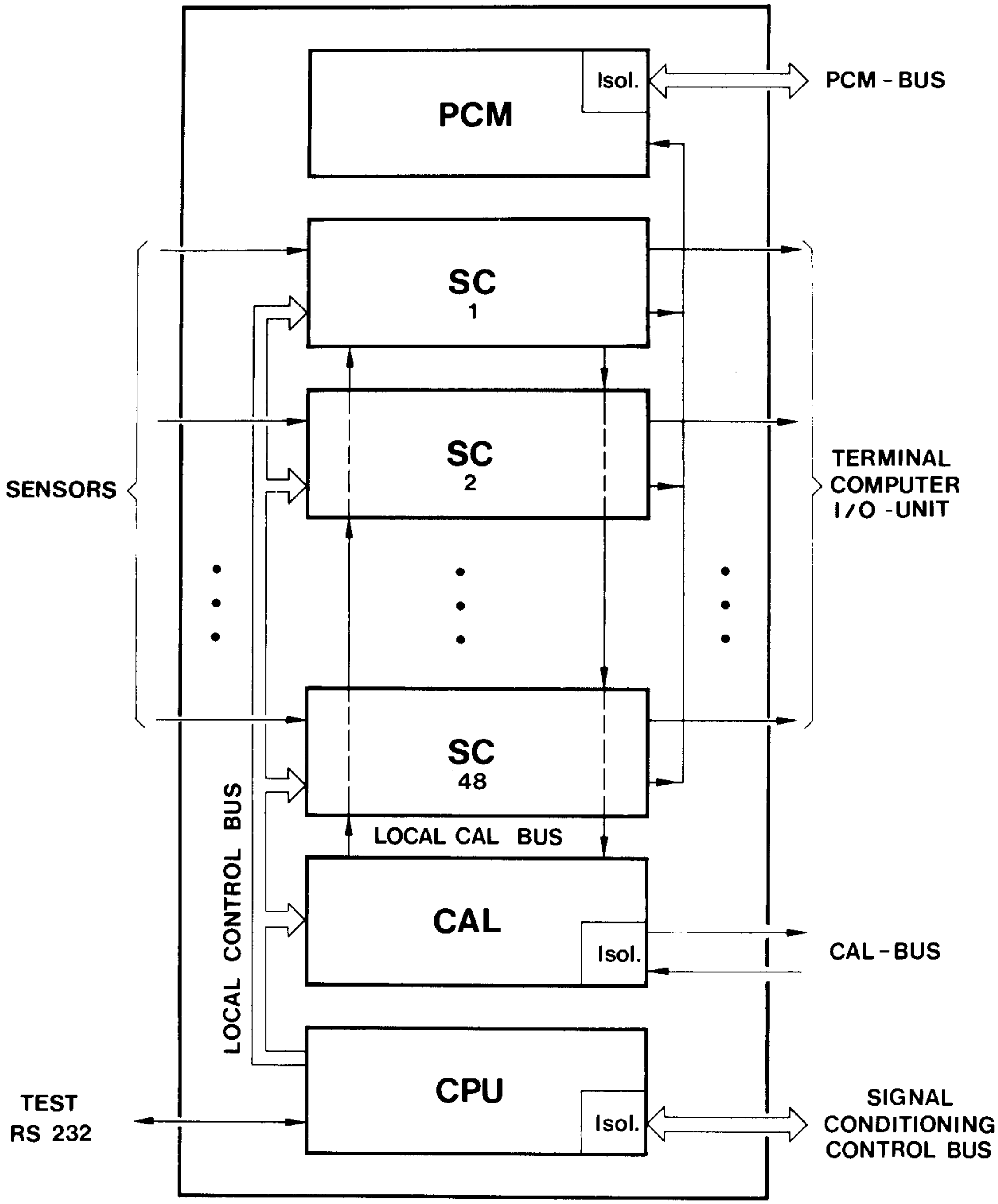

FIG. 3 - SIGNAL CONDITIONING UNIT BLOCK DIAGRAM

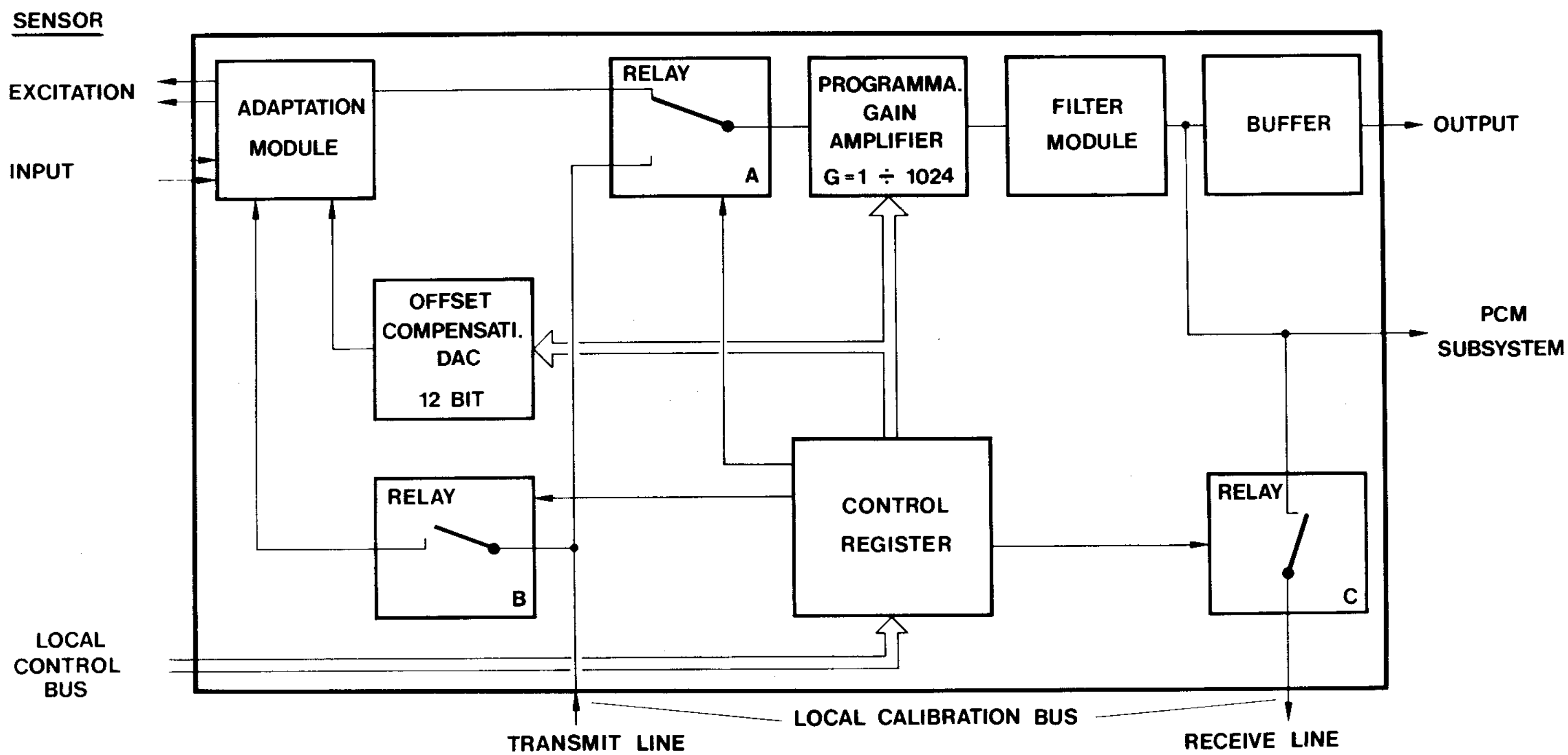

FIG. 4 - STANDARD ANALOG SIGNAL CONDITIONING CHANNEL FUNCTIONAL DIAGRAM

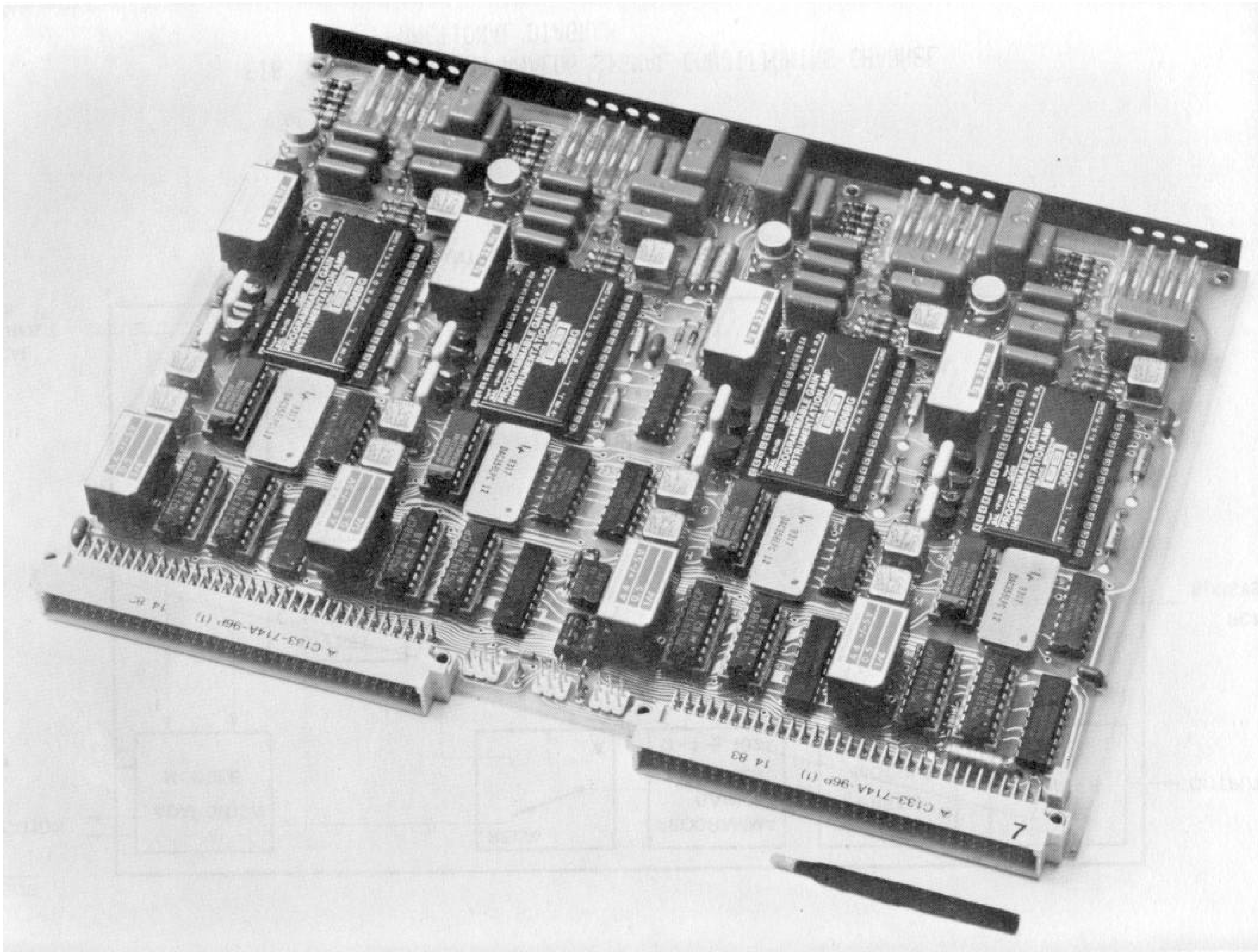

FIG. 5 - STANDARD ANALOG SIGNAL CONDITIONING BOARD (4 CHANNELS)

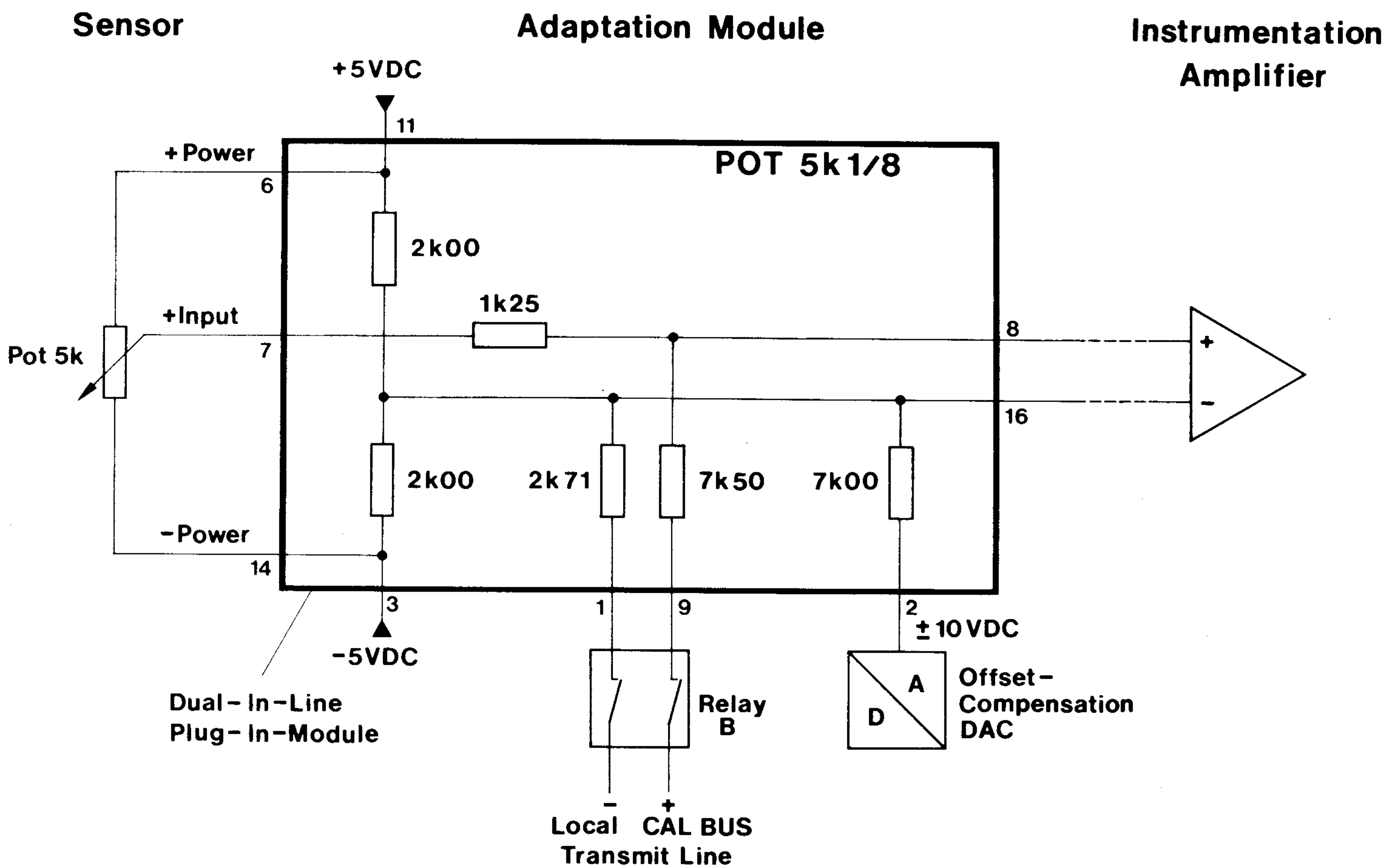

FIG. 6 - APAPTATION MODULE FOR 5K POTENTIOMETER SENSOR

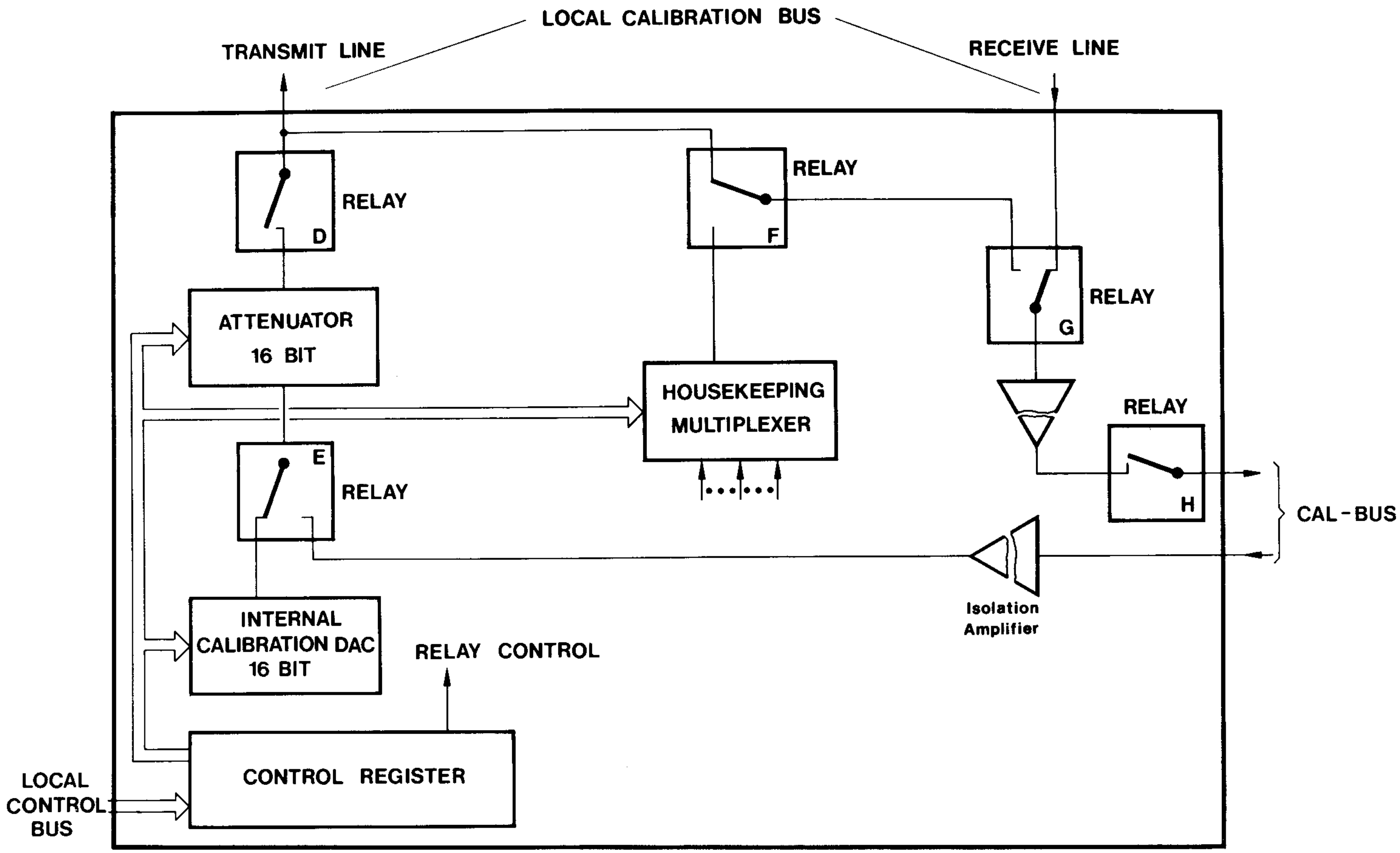

FIG. 7 - LOCAL CALIBRATION CENTRE BLOCK DIAGRAM

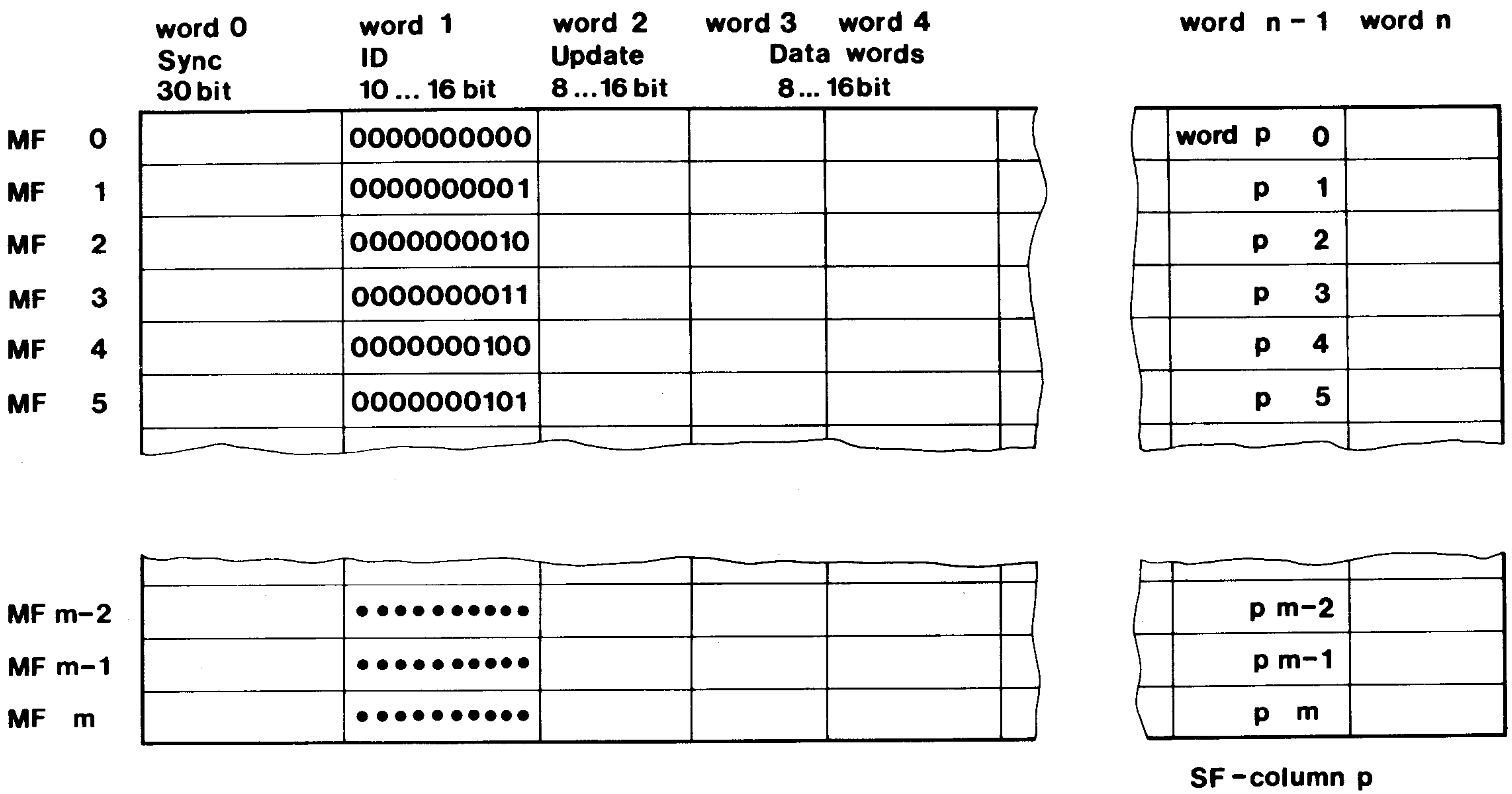

FIG. 8 - PCM FRAME: BLOCK OF M MAINFRAMES WITH N WORDS EACH, MAX. 14 SUBFRAME COLUMNS

ANALOG CHANNELS
BOX 01
CHECK/MODIFY CAL
07 | 10 | 100

PARAMETERS IN WITH ENTER, PAGE OFF WITH LF
CAL ON WITH DEL

0212 QUICK-LOOK

CHN	M/S	WNR	ZERO	G	C	MEASUREMENT NAME	QUICK-LOOK - 0 +
A01	MF	031	-0022	4	1/2	TRUE AIRSPEED	I********
A02	MF	032	0004	2	1/2	TOTAL AIR TEMP	I****
A03	S02	008	-0012	5	1/2	STATIC AIR TEMP	I***********
A04	S02	009	0054	3	1/2	BAROSET	**********I
A05	MF	104	1050	7	1/64	201.4 NORMAL ACC	*****I
A06	MF	095	0884	8	1/64	201.5 VERT. ACC	I**
A07	MF	096	-0104	9	1/64	201.6 LATERAL ACC	I*
A08	MF	062	0008	4	1/512	141.3 ROLL ANGLE	I***
A09	MF	063	-0073	5	1/512	141.4 PITCH ANGLE	*********I
A10	S01	004	-0156	2	1/2	110.1 GAS TEMP	I****
A11	S01	005	-0142	2	1/2	110.2 GAS TEMP	I*******
A12	S01	006	-0166	2	1/2	110.3 GAS TEMP	I******
A13	S01	007	-0085	2	1/2	110.4 GAS TEMP	I*********
A14	S01	008	0012	8	1/512	120.1 OIL TEMP	I*****
A15	S01	009	-0017	8	1/512	120.2 OIL TEMP	I*********
A16	S01	010	-0022	8	1/512	120.3 OIL TEMP	I*****
A17	S01	011	-0028	8	1/512	120.4 OIL TEMP	I***
A18	MF	006	-0430	6	1/64	SIM 01	********I

FIG. 9 - MENUE PAGE OF ANALOG CHANNELS WITH QUICK LOOK

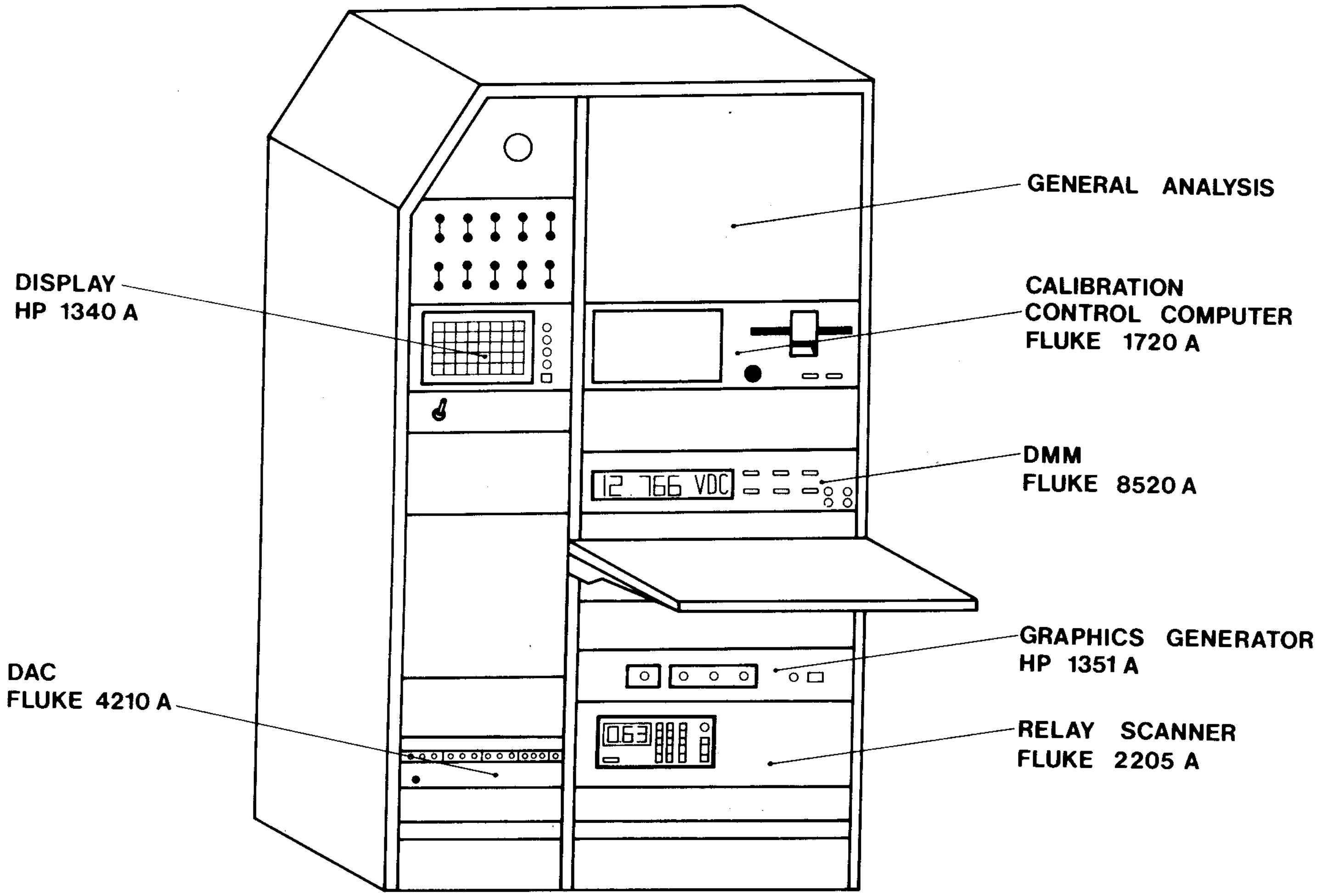

FIG. 10 - TEST AND CALIBRATION SYSTEM OPERATOR PANEL

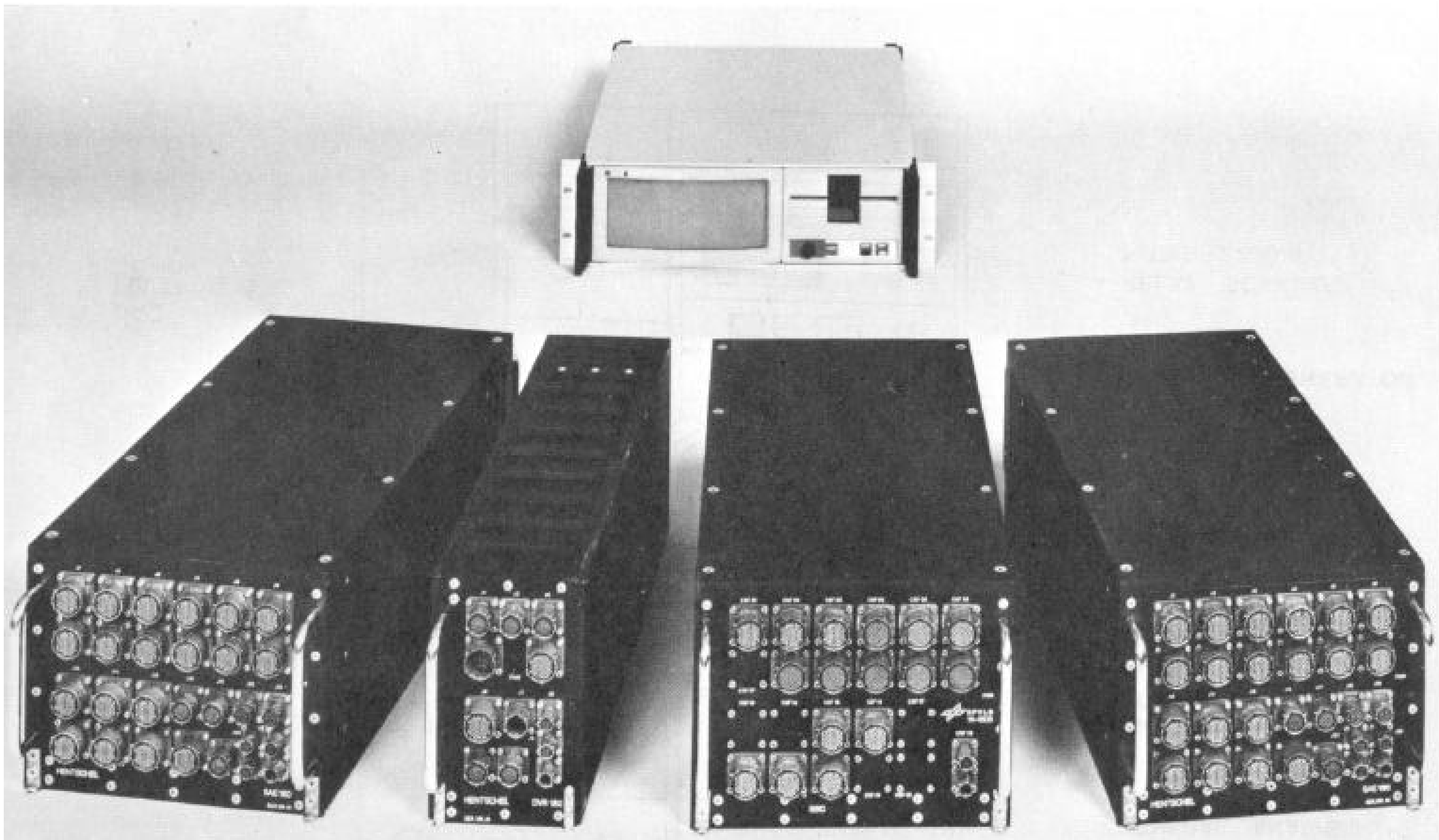

FIG. 11 - ATTAS MEASURING SYSTEM
FRONT (FROM LEFT): SC-UNIT, SC-MASTER UNIT, SSC-UNIT, SC-UNIT
BACK: CALIBRATION CONTROL COMPUTER