(NASA-CR-169799) NEW TECHNOLOGIES FOR RADIATION-HARDENING ANALOG TO DIGITAL CONVERTERS (Jet Propulsion Lab.) 64 p HC A04/MF A01 CSCL 09B

N83-17099

Unclas
G3/60 02603

New Technologies for Radiation-Hardening Analog to Digital Converters

Michael K. Gauthier

December 31, 1982

Prepared for
Defense Nuclear Agency
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL PUBLICATION 82-105

New Technologies for Radiation-Hardening Analog to Digital Converters

Michael K. Gauthier

December 31, 1982

Prepared for
Defense Nuclear Agency
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the Defense Nuclear Agency through an agreement with NASA.

ABSTRACT

Surveys of available Analog to Digital Converters (ADC) suitable for precision applications have shown that none have the proper combination of accuracy and radiation hardness to meet space and/or strategic weapon requirements. The objective of this study effort was to define a development program which will result in an ADC device which will serve a number of space and strategic applications. Emphasis was placed on approaches that could be integrated onto a single chip within three to five years.

ACKNOWLEDGEMENTS

This research project was carried out under the direction of Tom Ellis of the Naval Weapons Support Center (NWSC), contract monitor. Grateful acknowledgement is made for the assistance of: Alan Johnston, Dennis Russell, and Wes Will of the Boeing Radiation Effects Lab (BREL); John King, Keith Martin, Don Nichols, and Ron Weesner of JPL; Ron Pease and Jim Raymond of Mission Research Corporation; and special thanks are due to Bill Price, the JPL Task Manager; and to the many other individuals who have helped. Without the aid and expert knowledge of all these individuals, this project would not have been possible.

CONTENTS

Tables

SECTION 1

INTRODUCTION

1.1 OVERVIEW

The Analog to Digital Converter (ADC) provides the interface between the real world (environment) and the computer (data processing) world. In the computer world, data are manipulated in digital form. Digital data processing and communications have been finely tuned in order to provide flexibility and computational power.[1]

Analog to Digital Converters are the eyes and ears of control systems. It has been customary for these elements to be interfaced with (and controlled directly by) data processing elements. The advent of VLSI enables digital elements to be replicated at low cost. The addition of digital processing capabilities to ADC's increases their utility in digital control systems because it provides the capability for local decision making and signal processing. These factors can be utilized to improve the overall performance of the analog to digital conversion function, in particular, as well as substantially improve total control system performance. The addition of the digital elements for control and communications would reduce the processing speeds and complexities required by the major decision making processing elements in control systems, for example those controlling spacecraft, submarines or missiles.[2]

Surveys of available Analog to Digital Converters (ADC) suitable for precision applications have shown that none have the proper combination of accuracy and radiation hardness to meet space and/or strategic weapon requirements. The objective of this study effort was to define a development program which will result in an ADC device which will serve a number of space and strategic applications. Emphasis will be placed on approaches that can be integrated onto a single chip within 3-5 years.[3] Although a definite development program plan has not been developed, recommendations are stated herein which will lead to the availability of devices meeting the requirements of space and/or strategic weapons.

The ADC chip is rapidly developing in two directions: (1) the "basic ADC" on a monolithic chip, and (2) the "smart ADC" monolithic chip, which has not only the ADC, but also various microprocessor functions, RAM, ROM, I/O ports, and other circuitry to improve accuracy, extend operational range, and enhance functionality of the basic ADC.

There are individual applications best served by each type. Both types are being developed and should be monitored. The primary concern for the immediate future is in the basic ADC, but this study will not overlook the requirements for, and development of, the smart ADC.

1.2 SCOPE OF WORK

- Conduct a survey of system requirements
- Conduct a survey of commercial ADC's
- Survey new ADC concepts and techniques
- Analyze radiation degradation effects
- Conduct a trade-off analysis

SECTION 2

SYSTEM REQUIREMENTS

In conducting the survey of system requirements, system designers were asked to identify current ADC application problem areas, future applications, and what features they would like to see included on improved future ADC's (Ref. Appendix A).

There are numerous system benefits that can be gleaned from improved ADC chip systems (Ref. Table 1). These include incorporation of digital system processing and control into the ADC chip system which will improve the performance of the analog to digital conversion function and improve the overall control system performance. Improvements in the ADC linear performance can be achieved in the areas of speed, scaling, linearization, auto-recalibration and peak metering to note a few. These improvements would be realized by the capability to locally control the ADC processes and the capability to remember and apply logarithmic and other correction factors. The integration of higher level data processing capabilities within the ADC chip system enables these elements to provide enhanced control system processing with minimal increases in complexities.[4]

Table 1. System-Level Benefits of Advanced-Design ADC's[4]

SYSTEM FUNCTIONS:	ENHANCE SCIENCE RETURN	REDUCE DATA RATES	IMPROVE POINTING CONTROL	AUTONOMY/ DIAGNOSTICS	SIMPLIFY GROUND OPERATIONS	REDUCE		SIMPLIFY TESTING
						MASS	POWER	
ADC CAPABILITY								
ZERO SUPPRESSION/REFINED RESOLUTION	X		X					
PROGRAMMABLE GAIN	X		X	X				
PROGRAMMABLE CONVERSION SPEED (INCL UP TO "VERY FAST")	X		X					
PROGRAMMABLE ENCODING/ DATA WORD LENGTH	X	X		X				X
ADC WITH PRE-PROCESSING ADDED:								
ENGRG UNIT CONVERSION PER STORED CALIBRATION				X	X			X
COMPENSATION FOR CALIBRATION SHIFT			X	X	X			X
DATA SUPPRESSION		X		X	X			X
DATA AVERAGING	X	X		X	X			X
HIGH-SPEED PEAK/VALLEY SEARCH	X	X	X		X			X
MATHEMATICAL OPERATIONS ON 2 OR MORE SIGNALS		X	X	X	X			X
MODEL COMPARISON		X		X	X			X
ADC SENSOR-PECULIAR PROCESSING								
SELF-COMPRESSION FOR RADIATION-INDUCED DRIFT IN ADC	X		X	X	X			
LSI ADC + PREPROCESSOR + MEMORY + CONTROLLER ARCHITECTURE						X	X	

ORIGINAL PAGE IS
OF POOR QUALITY

SECTION 3

COMMERCIAL ADC'S

3.1 INTRODUCTION

Currently available commercial ADC's were investigated with specific interest in those best suited for aerospace applications[5]. Those meeting this requirement are listed in Table 2. The Jet Propulsion Laboratory (JPL) has recently completed research into the AD571 (including an extensive analysis of its radiation sensitivity using a Scanning Electron Microscope (SEM))[6,7,8], the AD574, the MN5210 family and the TDC-1001J. These ADC's are currently designed into Project Galileo and other aerospace projects.

The other ADC's listed have been evaluated but were not used on Project Galileo. The CMOS devices (AD7570 and ADC1210) were found to be too soft (100 Gy(Si)) while the TDC-1013J and TRADC87 did not meet the system requirements.

3.2 ADC SELECTION

The selection of the correct ADC requires specific information regarding the overall system and application before proceeding into the selection process. The required information includes:

- Resolution (bits)
- Power budget
- Conversion speed
- Radiation hardness
- Input/output requirements
- Accuracy
- Control interface
- System error budget
- Environmental conditions
- Purchasability

There are hundreds of different ADC's on the market but most of them are hybrids, too large, require too much power, too fast (flash converters), too slow, too few bits (low resolution), or do not otherwise meet the requirements for use in space.

Currently the total number of different ACD's available to spacecraft system designers is very limited.

Table 2. Currently Available Commercial ADC's

PART NO.	MFG.	BITS	POWER, mW	SPEED, μ sec	TOTAL DOSE RAD HARD Gy (Si)*	PROCESS
AD571	ADI	10	400	25	7.5×10^2	MONO I^2L BIPOLAR
AD574	ADI	12	400	25	3×10^2	2-CHIP, I^2L BIPOLAR
AD7570	ADI	10	40	40	10^2	CMOS
ADC1210	NSC	12	135	100	10^2	CMOS
MN5210	MICRO-NETWORKS	12	700	13	1.5×10^3	HYBRID BIPOLAR
TDC1001J	TRW	8	400	0.4	6×10^3	BIPOLAR MONOLITHIC
TDC1013J	TRW	10	600	1.0	?	BIPOLAR MONOLITHIC
TRADC87	TELEDYNE	12	1200	7	?	HYBRID

*THE GRAY (Gy) IS THE INTERNATIONAL STANDARD FOR EXPRESSING RADIATION FLUX AND FLUENCE, 1 Gy (Si) = 100 RAD (Si).

ORIGINAL PAGE IS OF POOR QUALITY

SECTION 4

NEW ADC CONCEPTS AND TECHNIQUES

Surveying new ADC concepts and techniques included a letter survey (Ref. Appendix B) to all known ADC manufacturers (Ref. Appendix C), reviewing current literature, and holding discussions with ADC designers to determine new concepts or processing techniques which could be applied to hardened designs. It was found that many companies are interested in marketing new ADC's in the next few years. Within the next five years, there will be a wide choice of ADC's available to designers. Most of these will not be designed with radiation hardness in mind, and will be relatively soft. A few companies, like Analog Devices and Advanced Micro Devices, are considering hardening techniques in their new designs but not specifically hardened devices. Honeywell and Sandia are designing devices that are hard. Their goals are 10 kGy(Si) minimum. Table 3 lists many of the soon to be commercially available ADC's.

4.1 AD573, ANALOG DEVICES, INC.[9]

The AD573 is a complete 10-bit successive approximation analog to digital converter consisting of a DAC voltage reference, clock, comparator, successive approximation register (SAR), and three-state output buffers — all fabricated to perform a full accuracy 10-bit conversion in 15 microseconds.

The AD573 incorporates the most advanced integrated circuit design and processing technology available today. The successive approximation function is implemented with I^2L (integrated injection logic). Laser trimming of the high stability SiCr thin film resistor ladder network at the water stage (LWT) insures high accuracy, which is maintained with a temperature compensated sub-surface Zener reference.

Operating on supplies of +5V and -12V to -15V, the AD573 will accept analog inputs of 0 to +10V, unipolar, or -5V to +5V, bipolar. A positive pulse on the CONVERT line initiates the 15 microsecond conversion cycle. DATA READY indicates completion of the conversion. HIGH BYTE ENABLE (HBE) and LOW BYTE ENABLE (LBE) control three-state output buffers. The AD573 interfaces to most 8- or 16-bit popular microprocessors without external buffers or peripheral interface adapters. The 10 bits of output data can be read as a 10-bit word or as 8- and 2-bit words.

The AD573S guarantees 10-bit accuracy and no missing codes from -55 degrees C to +125 degrees C. The AD573SD/1883B is screened in accordance with the Class B requirements of MIL-STD-883, Method 5004, and is offered in a 20 pin hermetically sealed ceramic DIP.

ORIGINAL PAGE IS OF POOR QUALITY

Table 3. Soon to be Commercially Available ADC's

PART NO.	MFG	BITS	POWER mW	SPEED μ sec	TOTAL† DOSE Gy (Si)	PROCESS	COMMENTS
AD573	ADI	10	350	15	1.5×10^3	I^2L	SIMILAR TO AD571. μP BUS INTERFACE
ADC0831	NSC	8	10	12	10^2	CMOS	4 DEVICE FAMILY, UP TO 8 INPUTS
AM6108	AMD	8	600	0.5	3×10^3	BIPOLAR	TRI-STATE OUTPUT
AM6148	AMD	8	600	0.9	3×10^3	BIPOLAR	SIMILAR TO AM6108
AM6112	AMD	12	600	3.0	3×10^3	BIPOLAR	TRI-STATE OUTPUT. AVAILABLE LATE 1982
CX899	SONY	16	1500	25	10^3	I^2L	AUDIO APPLICATIONS. DUAL SLOPE
TA607	SANDIA	8	10	30	10^4	CMOS-RH	RADIATION HARD PROCESS. AVAILABLE MID 1983
ADXXX	BURR-BROWN	12	?	?	10^3	BIPOLAR	μP BUS INTERFACE. SAR
ADXXX	HARRIS	10	?	20	10^3	BIPOLAR	AUDIO APPLICATIONS. AVAILABLE MID 1983
ADXXX	HONEYWELL	10	?	20	10^4	BI-MOS	μP BUS INTERFACE. AVAILABLE MID 1983
ADXXX	INTEL	10	?	20	30	NMOS	μP ON CHIP
ADXXX	MOTOROLA	12	?	15	10^2	CMOS	SAR. AVAILABLE MID 1984
ADXXX	NEC	11	270	?	30	NMOS	AUDIO APPLICATIONS. ADC. DAC. FILTER. ETC. ON CHIP

† ESTIMATED HARDNESS

ORIGINAL PAGE IS
OF POOR QUALITY

4.2 ADC 0831, NATIONAL SEMICONDUCTOR CORPORATION[10]

The ADC0831 series are 8-bit successive approximation ADC's with a serial I/O and configurable input multiplexers with up to 8 channels. The serial I/O is configured to interface with standard shift registers or microprocessors.

The 2-, 4- or 8-channel multiplexers are software configured for single-ended or differential inputs as well as channel assignment.

The differential analog voltage input allows increasing the common-mode rejection and offsetting the analog zero input voltage value. In addition, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bits of resolution.

The ADC0831 series is easily interfaced to all microprocessors or operates in a "stand-alone" mode. It may be operated ratiometrically or with a 5 V_{DC} voltage reference. No zero or full-scale adjustments are required. There is addressable logic for 2, 4, or 8 channel multiplexer options.

The ADC0831 series guarantees 8-bit accuracy and no missing codes from -55 degrees C to +125 degrees C and is offered in the hermetic packages (Ref. Table 4).

Table 4. Multiplexer Package Options

Part Number	Number of Analog Channels		Number of Package Pins
	Single-Ended	Differential	
ADC0831	1	1	8
ADC0832	2	1	8
ADC0834	4	2	14
ADC0838	8	4	20

4.3 AM6108, ADVANCED MICRO DEVICES, INC.[11]

The AM6108 is a completely monolithic, high-speed, microprocessor-compatible ADC that converts analog input signals into 8-bit digital output code in less than 1 microsecond. The digital output code is selected by the user as either 2's complement or offset binary. Due to the high-speed conversion, "WAIT" states are not longer necessary for most microprocessor-based data conversion/acquisition systems or instrumentation.

The AM6108 consists of an 8-bit DAC, a high-speed comparator, SAR, a 2.5V reference and control logic. The 2.5V reference is implemented utilizing the bandgap voltage of silicon. The digital outputs are three-state buffers with the standard TTL levels for logic 1 and logic 0. This allows the user to interface with the microprocessor data bus conveniently.

Internal scaling resistors enable the AM6108 to handle input signal ranges of 0 to +5V, ±5V, and 0 to +10V with the device operating at ±5V supplies.

The AM6108 uses linear differential logic (LDL) to implement the switching functions. LDL is a non-saturating form of logic quite similar to emitter coupled logic (ELC). However, it offers higher performance with increased density since the logic cell is smaller. LDL speed-power product is also significantly lower compared to that of ECL. Level translators are used to achieve TTL-level compatibility at digital inputs and outputs.

The AM6108DM guarantees 8-bit accuracy and no missing codes from -55 degrees C to +125 degrees C and is offered in a 28 pin hermetic package.

4.4 AM6148, ADVANCED MICRO DEVICES, INC.[12]

The AM6148 is a microprocessor-compatible 8-bit high-speed ADC. The AM6148 is the first fully monolithic high-speed ADC to include a precision reference, DAC, comparator, SAR, scale resistors, three-state output buffers, and control logic. The AM6148 is capable of completing an 8-bit conversion in under one microsecond and can handle input voltage ranges of 0V to +10V, 0 to +5V, and ±5V without external components. With appropriate external resistors, the user can program the device to operate on other input signal ranges (2 or 3 precision resistors are required). Full 8-bit performance is guaranteed over temperature. The device has three-state outputs for bus compatibility and two status outputs — one a standard TTL signal and the other available as a status output on the data bus.

The AM6148 is useful in microprocessor-based systems or can be used in a stand-alone mode. The conversion time is short enough to allow most microprocessors to accept data immediately after requesting a conversion.

The AM6148 is the same as the AM6108 except some of the pins, including Data Status, positive reference, and the inventing comparator input, have been deleted. The AM6148 is guaranteed for 8-bit accuracy and no missing codes from -55 degrees C to +125 degrees C and is offered in a 24 pin hermetic package.

4.5 AM6112, ADVANCED MICRO DEVICES, INC.[13]

The AM6112 is the first fully monolithic microprocessor-compatible 12-bit high-speed ADC. The AM6112 high-speed ADC contains a precision reference, DAC, comparator, SAR, scale resistors, three-state output buffers, and comprehensive control logic, enabling the device to be interfaced with a variety of microprocessors. The AM6112 is capable of completing a 12-bit conversion in under three microseconds and can handle input voltage ranges of 0 to +10V, 0 to +5V, and ±5V without external components.

ORIGINAL PAGE IS
OF POOR QUALITY

The AM6112 has four modes of operation, two microprocessor, one DMA, and a "stand-alone" mode. These modes are software programmable, except for the stand-alone, which is pin selectable.

The AM6112 is easily interfaced with 8- and 16-bit microprocessors. It is guaranteed monotonic with no missing codes over the full operating range of -55 degrees C to +125 degrees C. This ADC is packaged in a 24 pin hermetic DIP.

4.6 CX899, SONY CORPORATION[14]

The CX-899 is a newly produced ADC developed for Pulse Code Modulation (PCM) applications. This ADC uses the dual slope integration technique and boasts fine monotonicity and low noise.

This I^2L ADC consists of a clock buffer, clock synchronous comparator, electric current source, TTL output, interface, and other circuitry.

The CX-899 is capable of completing a 16-bit conversion in 25 microseconds and can handle input voltage ranges from 0 to +16 volts without external components. This ADC can operate over the temperature range of -10 degrees C to +60 degrees C and is offered in a 28 pin DIP of molded epoxy resin.

4.7 TA607, SANDIA NATIONAL LABORATORIES[15]

The TA607 is an 8-bit successive approximation ADC utilizing Si-Gate CMOS technology and is implemented on a 109 × 109 mil chip. The circuit was designed as a test chip and consists of an 8-bit switched capacitor array, offset cancelled comparator, successive approximation and control logic, and two operational amplifiers intended for characterization.

The circuit functions both as a sample/hold and ADC. When the convert command is high ($\sim$6 μs), the input voltage is stored in the capacitor array with the comparator offset to allow for offset cancellation. When the convert command goes low, the input is switched open, the input voltage is held on the capacitor array, and the conversion begins. The bit trials occur on half cycles of the clock ($\sim$2 μs per bit) and the busy signal ($\overline{EOC}$) goes high on the positive transition of convert command and goes low when the conversion is complete. The 8 bits of conversion date are held at the outputs until the next leading edge of the convert command.

The converter is unipolar with input range of V_{IN} = 0 to V_{REF}, where V_{REF} (5.0V ±0.5V) is supplied externally. The comparator bias point V_B-Comp ($\sim$7V) can be implemented with an external resistor tied to V_{DD}, and the amplifier bias point V_B-Amp should be grounded. If the amplifiers are not to be used, then V_M should also be grounded to kill the amplifier current; otherwise $V_M \simeq$ -4 volt. The current drain from V_{DD} ($\sim$10V) is about 1 mA when the amplifiers are not drawing current; otherwise the amplifiers draw about 1 mA each.

This ADC is offered in a 28 pin DIP.

4.8 ADC TECHNIQUES

For the purpose of this study, ADC techniques using fast conversion rates, good accuracy, and resolution for general purpose applications were of the main interest. Of the dozens of ADC techniques available[16], those of greatest interest to this study are described in Table 5. The technique most often used for the type of ADC's investigated in this study was the Successive Approximation Register (SAR). The SAR technique is described by Analog Devices as:[17]

> <u>Successive Approximations</u>
>
> Successive approximations is a high speed method of comparing an unknown against a group of weighted references. The operation of a successive approximations A/D converter is generally similar to the orderly weighing of an unknown quantity on a precision chemical balance, using a set of weights such as: 1 gram, 1/2 gram, 1/4 gram, 1/8 gram, 1/16 gram, etc. The weights are tried in order, starting with the largest. Any weight that tips the scale is removed. At the end of the process, the sum of the weights remaining on the scale will be within one LSB of the actual weight (±1/2 LSB, is the scale is properly biased).

ORIGINAL PAGE IS
OF POOR QUALITY

Table 5. Practical ADC Techniques

TECHNIQUE	ADVANTAGES	DISADVANTAGES	TYPICAL APPLICATIONS
CHARGE BALANCE	• GOOD DIFFERENTIAL LINEARITY • EXCELLENT LINEARITY • MODERATE COST • GOOD INTEGRATION CHARACTERISTICS • INDEPENDENT OF CLOCK RATE	• DIFFICULT TO AUTOZERO • MORE COMPLEX FOR BIPOLAR USAGES • RELATIVELY SLOW	• PORTABLE DVMs
DUAL SLOPE	• GOOD DIFFERENTIAL LINEARITY • EXCELLENT LINEARITY • EASY TO AUTOZERO • WIDE DYNAMIC RANGE AND RESOLUTION • INDEPENDENT OF MANY COMPONENT VARIATIONS • INDEPENDENT OF CLOCK RATE	• RELATIVELY SLOW	• GENERAL PURPOSE DVMs • FLOATING TRANSDUCER FRONT END
PARALLEL THRESHOLD (FLASH) AND (SEQUENCE)	• FASTEST POSSIBLE • BASICALLY LINEAR AND MONOTONIC	• MULTIPLICITY OF ELEMENTS • HIGH POWER • PRACTICALLY LIMITED RESOLUTION	• TV VIDEO DIGITIZING • RADAR DIGITIZING • TRANSIENT ANALYSERS
SHIFT PROGRAMMED SUCCESSIVE APPROXIMATION	• FAIRLY FAST • GOOD AVAILABLE ACCURACY AND RESOLUTION • REASONABLY ECONOMICAL • MODERATE POWER REQUIREMENT	• REQUIRES S/H FOR DYNAMIC SIGNALS • ACCURACY AND ULTIMATE RESOLUTION DEPENDS ON RESISTOR WEIGHTING AND CIRCUIT STABILITY	• GENERAL APPLICATION • AUDIO DIGITIZING • ANALYTICAL INSTRUMENT • MEDICAL INSTRUMENTS (EEG AND EKG)
TRIPLE SLOPE	• AS ABOVE FOR DUAL SLOPE • BUT FASTER	• LIMITED TO MODERATE SPEED	• HIGH SPEED DVM • MODERATE SPEED HIGH DIFFERENTIAL LINEARITY HIGH RESOLUTION A/D

SECTION 5

RADIATION ANALYSIS OF ADC TECHNOLOGIES

A comparison of the various ADC fabrication technologies to their radiation hardness in various radiation environments is given in Table 6. These technologies vary from very soft to very hard. They also vary from environment to environment.

5.1 BI-POLAR

The current bi-polar technology is one of the overall radiation-hardest technologies for ADC's. A number of ADC's are currently available in bi-polar.

5.2 I^2L

The most popular and overall radiation-hardest technology is I^2L. A wide range of ADC's are currently available in I^2L.

5.3 CMOS

Standard CMOS is a popular technology but it is radiation-soft. Many ADC's have been designed in CMOS. The recently developed radiation-hardened process is as hard as the hardest bi-polar. The first radiation-hardened CMOS device will be the TA607 from Sandia National Laboratories (Ref. Table 2) which will be available next year. Other companies plan to use the radiation-hardened process for future devices.

5.4 NMOS

This technology is very soft and shows little promise of being hardened. There are a number of manufacturers making ADC's in NMOS.

5.5 PMOS

This technology, like NMOS, is very soft and shows little promise of being hardened. There are a number of manufacturers making ADC's in PMOS.

5.6 SOS

SOS is soft to total dose but hard to other environments. Additional development of SOS should increase its total dose hardness to the same levels as radiation-hardened CMOS. Several manufacturers claim to have made SOS ADC's, but the data sheets and device samples were never received for evaluation.

ORIGINAL PAGE IS
OF POOR QUALITY

Table 6. Radiation Analysis of ADC Technologies

TECHNOLOGY	SPEED	TOTAL DOSE Gy (Si)	DOSE RATE Gy (Si)/sec	NEUTRON N/cm^2	SINGLE EVENT UPSET (SEU)	ADVANTAGES	DISADVANTAGES
BIPOLAR	HIGH	$10^2 - 10^4$	10^8	$10^{14} - 10^{15}$	FLIPS	HIGH SPEED ANALOG STABLE BAND GAP VOLT REFERENCE	LARGE SIZE HIGH POWER
I^2L	HIGH	$10^3 - 10^4$	10^7	$10^{13} - 10^{14}$	LATCHES	SAME AS ABOVE SMALL, LOW POWER	
CMOS	LOW	$10^2 - 10^4$	10^7	$10^{15} - 10^{16}$	LATCHES	LOW POWER SMALL SIZE	LOW SPEED (FUTURE CMOS WILL BE FASTER
NMOS	LOW	$10^1 - 10^2$	10^6	$10^{15} - 10^{16}$	LOC/MOS FLIPS	LOW POWER, SMALL SIZE	RAD SOFT LOW SPEED
PMOS	LOW	$10^1 - 10^2$	10^6	$10^{15} - 10^{16}$	—	LOW POWER, SMALL SIZE	RAD SOFT LOW SPEED
SOS	MED	$2 \times 10 - 10^2$	10^8	$10^{15} - 10^{16}$	NO LATCH	HARD TO RAD TRANSIENTS AND LATCHUP	CHANNEL LEAKAGE. EXPENSIVE
BI-MOS (I^2L/CMOS)	MED	10^4	10^7	$10^{13} - 10^{14}$	—	ANALOG AND DIGITAL OPTIMIZED ON SAME CHIP	NEW DEVELOPMENT
GaAs	HIGH	$>10^5$	$>10^8$	$>10^{15}$	—	HIGHEST SPEED INSTRINSICALLY RAD HARD	NEW DEVELOPMENT EXPENSIVE

5.7 BI-MOS

A relatively new technology which is radiation-hard is Bi-MOS. This is a combination of I^2L and CMOS on the same chip for optimization of the analog and digital circuits. It has all the advantages of I^2L and radiation-hardened CMOS (when made with the radiation-hardened CMOS process). Honeywell is very active in this technology and plans to have its ADC available for testing during 1983. Several other manufacturers, including Analog Devices, Inc., are planning to use this technology in the near future.

5.8 GaAs

This may be the best technology for future ADC's. GaAs is very hard to all radiation environments. Currently there are no sources of ADC's and none are expected for five to ten years.

SECTION 6

TRADE-OFF ANALYSIS

Based on the information derived from this study, a set of promising development options can be recommended. Each recommendation is listed in Table 7. Each option is rated by overall performance (including radiation hardness), availability, vendor commitment to radiation hardness, developmental cost, and the total risk involved to "fly" the ADC.

6.1 CURRENT APPLICATIONS

For the immediate design needs for the radiation environment, there are two manufacturers of the latest design ADC's. Both claim their devices will be available in 1982.

6.1.1 8-bit

For 8-bit applications, the AMD AM6108 and AM6148 should be considered. This family of devices also includes the AM6112 12-bit ADC. Initial radiation tests of the AM6148 indicate the device is hard to 3×10^3 Gy(Si).

6.1.2 10-bit

Applications requiring a 10-bit ADC should consider the ADI-AD573. This device has not been radiation tested but should hard to at least 1.5×10^3 Gy(Si).

6.1.3 12-bit

Designers requiring a 12-bit ADC should consider the AM6112. This device is part of the AMD ADC family noted above (in Section 6.1.1). The radiation hardness of this device should be the same as for the AM6148.

6.1.4 16-bit

When a 16-bit ADC is required, consideration should be given to the Sony CX899. This device has not been radiation tested because of the lack of technical data on its operation. It should be hard to at least 1×10^3 Gy(Si).

6.2 FUTURE APPLICATIONS

Within the next year both Honeywell and Sandia National Laboratories should have their entries into the ADC market and both devices should be hard.

ORIGINAL PAGE IS
OF POOR QUALITY

Table 7. Trade-off Analysis

FABRICATION TECHNOLOGY	ADC TECHNIQUE	BITS	ESTIMATED HARDNESS Gy(Si)	AVAILABLE DATE	COMPANY	CURRENT FUNDING	RISK
I^2L	SAR	10	1.5×10^3	1982	ADI	CORPORATION	SLIGHT
BIPOLAR	SAR	8-12	3×10^3	1982	AMD	CORPORATION	SLIGHT
BIPOLAR	DUAL SLOPE	16	1×10^3	1982	SONY	CORPORATION	SLIGHT
BI-MOS	SAR	10	1×10^4	1983	HONEYWELL	CORPORATION	MODERATE
CMOS-RH	SAR	8	1×10^4	1983	SANDIA	CORPORATION	MODERATE
BIPOLAR	SAR	10	2×10^3	1985	PMI	NONE	HIGH
CMOS-RH	SAR/DUAL SLOPE	10-12	1×10^4	1985	LINEAR TECH-NOLOGY	NONE	HIGH

6.2.1 Honeywell

Honeywell is developing a 10-bit device in its Bi-MOS process. This device has not been radiation tested, but it is expected to be hard to 1×10^4 Gy(Si).

6.2.2 Sandia National Laboratories

Sandia is developing an 8-bit device in its Rad-Hard CMOS process. Initial radiation test results indicate this service will be hard to 1×10^4 Gy(Si).

6.2.3 Other Companies

In several years (about 1985), two companies, currently not building ADC's, plan to have radiation-hardened devices on the market. The companies, PMI and Linear Technology, are both experienced in the design and fabrication of radiation-hardened devices.

6.2.3.1 PMI. PMI is planning a 10-bit, bi-polar device using the SAR technique. It is expected to be hard to at least 2×10^3 Gy(Si). Currently there is no funding for the project. This company would be interested in working with outside funding sources in the development of the ADC.

6.2.3.2 Linear Technology. Linear Technology feels that the development of radiation-hardened ADC's should be done in Rad-Hard CMOS using a unique SAR/Dual Slope technique. This company would like to develop a 10- to 12-bit device for an outside funding source. It is expected that the device would be hard to 1×10^4 Gy(Si).

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Future analog to digital converters complying with space and/or strategic weapon requirements will be developed as a result of this study. Bit configuration and operating speed will be defined and a configuration with optimized special features to ease equipment design and operation will be recommended. Currently used and future process technologies are being evaluated and a process will be selected to optimize performance and comply with current space and/or strategic requirements for radiation hardening. It is intended that this device be suitable for a wide range of equipment and systems applications.

7.2 RECOMMENDATIONS

For the immediate needs, the AMD AM6108 and AM6148 should be considered for 8-bit application, the ADI AD573 for 10-bit applications, the AMD AM6112 for 12-bit applications, and the Sony CX899 for 16-bit applications. These are all monolithic devices and should be hard to at least 10^3 Gy(Si). (Radiation test results on these devices will be available from JPL in the near future.) Increased hardness may be obtained on these devices by "tweaking" the manufacturing process. With vendor cooperation, process variations may be made that will improve the typical hardness of the devices by a factor of two to four times.

For the needs within the next 3-5 years, it is recommended that:

1. Those companies interested in ADC development be monitored and assisted.

2. The development of new radiation-hardened ADC's be encouraged.

3. The inclusion of radiation hardening design rules into new ADC designs be pursued.

4. Radiation testing of all candidate ADC devices be performed.

5. The interface between users and the ADC manufacturers be continued.

REFERENCES

1. C. Sabolis, "Understanding Data Converters," 1980 Product Guide and Applications Manual, Micro-Networks Company, Worcester, Mass. (1980), p. 2-1.

2. E. Greenberg, "Reflections on ADC in the Era of VLSI," JPL Interoffice Memo (3172-82-001), 5 January 1982 (internal document).

3. M. K. Gauthier, J. J. King, D. K. Nichols, and R. L. Weesner, "Future Radiation Hardened Analog to Digital Converters," Government Microcircuit Applications Conference Digest of Papers, Volume IX. November 1982, pp. 62-63.

4. H. N. Norton, "Possible Spacecraft System-Level Benefits of Advanced-Design Analog-to-Digital Converters (ADC's)," JPL INteroffice Memo (3134-82-003), 6 January 1982 (internal document).

5. W. E. Price, K. E. Martin, D. K. Nichols, M. K. Gauthier, and S. F. Brown, "Total-Dose Radiation Effects Data for Semiconductor Devices," JPL Pub. No. 81-66, Volume II, December 1981.

6. M. K. Gauthier, J. Perret and K. C. Evans, "SEM Analysis of Ionizing Radiation Effects in an Analog to Digital Converter (AD571)", IEEE Transaction on Nuclear Science (Vol. NS-28, No. 6), December 1981, pp. 4051-5.

7. M. K. Gauthier and A. G. Stanley, "Methods for Analyzing Radiation Sensitivity of Integrated Circuits," U.S. Patent 4,172,228, October 23, 1979.

8. C. G. Thomas and K. C. Evans, "The SEM as a Diagnostic Tool for Radiation Hardness Design of Microcircuits," Scanning Electron Microscopy, Vol. I, (1979), pp. 735-9.

9. Data-Acquisition Databook 1982, Analog Devices, Inc. (1980), pp. 11-31 through 11-37.

10. ADC0831, ADC0832, ADC0834, ADC0838 8-bit Serial I/O A/D Converters with Multiplexer Options, National Semiconductor Corp. (June 1982).

11. AM6108 APP NOTE, Advance Micro-Devices (1982).

12. AM6148 Preliminary Data, Advance Micro-Devices (1982).

13. AM6112 Preliminary Data, Advance Micro-Devices (February 1982).

14. Specification of CX-899 (Preliminary Data Sheet), Sony Corp. (1982).

15. TA607 CMOS Charge Redistribution Successive Approximation A/D (Preliminary Data Sheet), Sandia National Laboratories, (1982).

16. B. M. Gordon, "Linear Electronic Analog/Digital Conversion Architectures, Their Origins, Parameters, Limitations, and Applications," IEEE Transactions on Circuits and Systems, CAS-25, No. 7, (July 1978).

17. "Orientation: Analog-to-Digital Converters," Data Acquisition Data Book 1982, Vol. 1, Integrated Circuits, Analog Devices, Inc., Norwood, Mass. (1982) p. 11-8.

APPENDIX A

JET PROPULSION LABORATORY

4 Jan. 1982

A/D CONVERTER STUDY

POSSIBLE SPACECRAFT SYSTEM-LEVEL BENEFITS OF ADVANCED-DESIGN ANALOG-TO-DIGITAL CONVERTERS (ADC's)

Harry N. Norton

The overall objective of the ADC Study is to "define a development program which will result in an A/D converter device which will serve a number of space and strategic applications". A survey of system requirements is one of the tasks that were requested to be undertaken as part of this study. The material contained in this report addresses a subset of this task,i.e., the benefits that could potentially be offered to spacecraft systems by specific characteristics of advanced-design ADC's and by incorporating specific additional capabilities into such devices.

A. INTRODUCTION

The purpose of an ADC is to convert an analog signal into a digital signal. More specifically, in spacecraft data systems an ADC converts a sample of an analog signal into a digital data word, usually in binary code. In most cases, the analog signal is the output of a sensor; it is a voltage whose amplitude, waveshape, frequency, etc., are representative of the measurand (measurand is defined as "the physical quantity, property, or condition which is measured").

The sensor can be one of the following:
a. a "science" instrument (e.g., imager, plasma analyzer, infrared radiometer)
b. a control-system sensor (e.g., target sensor, horizon sensor, inertial sensor)
c. an "engineering" transducer used to monitor critical parameters in spacecraft subsystems; such parameters include voltages, currents, pressures, temperatures, forces and accelerations. Engineering measurements made within a science instrument are often referred to as "housekeeping" measurements.

It has been customary, in spacecraft systems, to provide a dedicated ADC in all or most science instruments. Control systems may use their sensor outputs in analog or digital form. The signals from engineering transducers, however, are usually multiplexed into an "engineering frame" within which some measurements are sampled more frequently, others less frequently.

This portion of the study considers primarily sensor-dedicated ADC's. It addresses features and characteristics of ADC's that operate on the output of only one sensor, whether this be a science instrument, a control-system sensor, or an engineering transducer.

B. SUMMARY

Benefits can accrue to the spacecraft system, including the associated ground operations and system-level testing, if the advanced-design ADC can provide one or more of the following:

a. Enhancing Features
   Enhance science return
   Improve pointing control
   Facilitate spacecraft autonomy and/or diagnostics

b. Simplifying Features
   Reduce data volume and/or data rates
   Simplify ground operations
   Simplify testing

c. Cost Reduction
   Reduce spacecraft costs
   Reduce ground operations cost

Specific features and capabilities that could be provided by advanced-design ADC's were examined and tested against the benefits listed above. Considerations included ADC programmability, the addition of an analog preprocessor and/or a digital postprocessor, and ADC architecture. The results of this examination are summarized in Table 1. It should be noted that the absence of an "X" in a column indicates either no effect or an adverse effect. The individual features and new capabilities are explained in Section C. of this report.

A simplified data-flow block diagram is shown in Figure 1. The sensor can be, e.g., a detector of electromagnetic or particle radiation, closely coupled to its preamplifier; it can be a self-generating transducer such as a thermopile;

TABLE 1. POSSIBLE SYSTEM-LEVEL BENEFITS OF ADVANCED-DESIGN ADC's

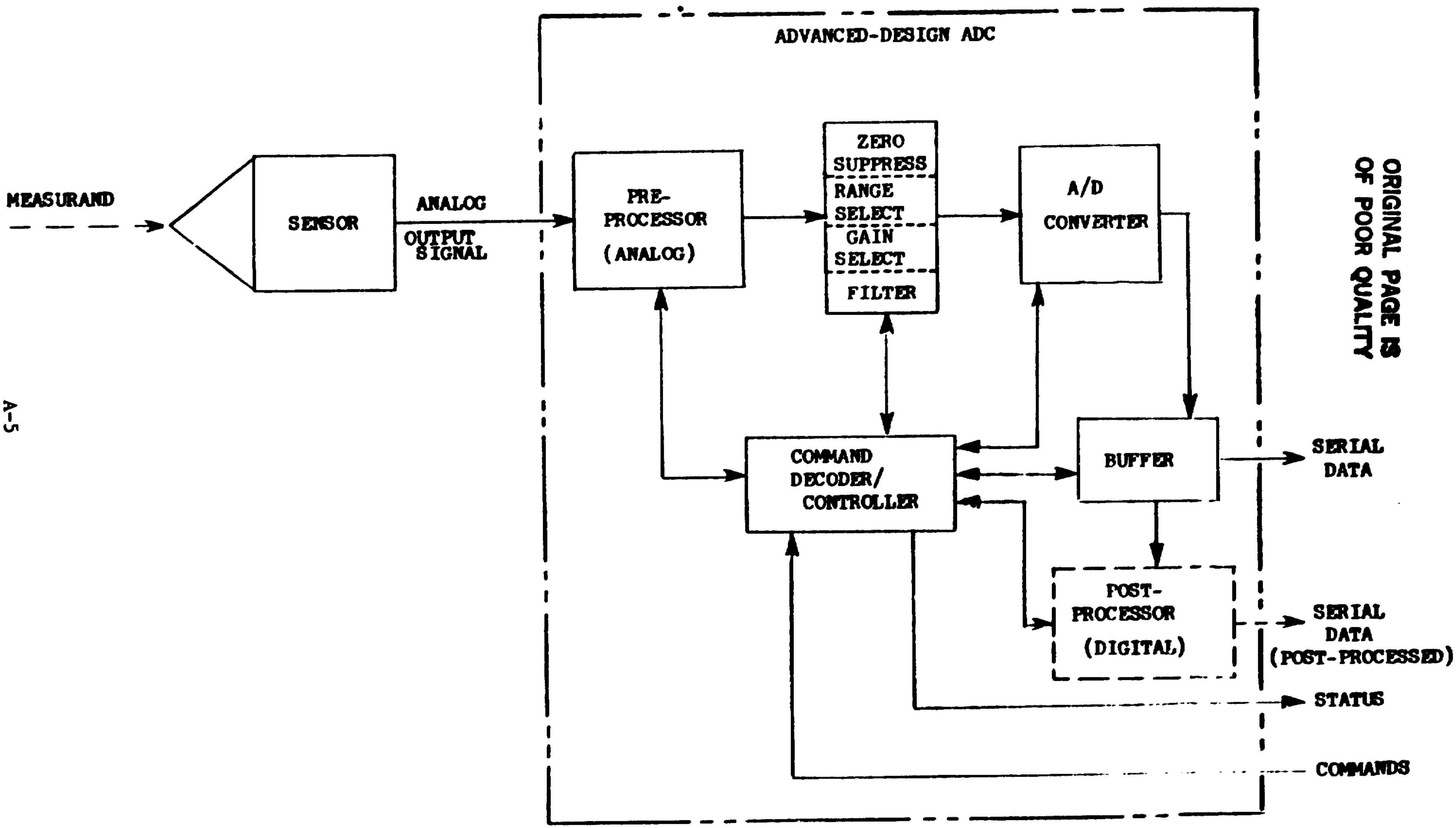
Spacecraft System Functions:	Enhancing Features			Simplifying Features			Reduce Cost	
Candidate ADC Features and Capabilities:	Enhance Science Return	Improve Pointing Control	Facilitate S/C Autonomy and/or On-board Diagnostics	Reduce Data Volume/ Rates	Simplify Ground Operations	Simplify Testing	S/C	Ground
1. Programmable Gain	X	X	X					
2. Programmable Zero Suppression	X	X					X	
3. Programmable Range Selection	X		X				X	
4. Programmable Filtering			X		X			
5. Programmable Sampling Rate	X	X	X					
6. Programmable Conversion Speed	X	X						
7. Programmable Encoding/Data Word Length	X		X	X		X	X	
8. Engrg.Unit Conversion per Stored Calibr.			X		X	X		X
9. Compensation for Calibration Shift		X	X		X	X		X
10. Data Suppression			X	X	X	X		X
11. Data Averaging	X		X	X	X	X		X
12. High-Speed Peak/Valley Search	X	X	X *)	X	X	X		X
13. Mathematical Operations		X	X	X	X	X		X
14. Model Comparison			X	X	X	X		X
15. ADC Self-Compensation for Drift	X	X	X		X			X

*) can be low-speed minimum/maximum search

ORIGINAL PAGE IS OF POOR QUALITY

or it can be a passive transducer such as a strain-gage pressure or force transducer that requires external excitation power. The sensor may also incorporate signal-conditioning circuitry such as linear or logarithmic amplifiers, voltage dividers, resistance bridges, and ac-to-dc converters.

The elements of the advanced-design ADC shown in the diagram are those that would typically be required to provide the candidate features and capabilities discussed in Section C. of this report. Whereas it appears that many, possibly all, of the features could be provided by an analog preprocessor, it has not yet been determined whether it would be simpler or more cost-effective to have at least some of the features provided by a digital postprocessor. Hence, the diagram includes both of these elements. Gain and range selection, zero suppression and filtering are typical for those functions immediately associated with the A/D converter itself. The comman detector/controller accepts serial commands and controls all state changes and other functions within the ADC. It may also incorporate a memory, such as a PROM, where commands can be stored for the purposes of autonomous ADC operation. Additionally, the controller sends status information to the spacecraft data system. The preprocessor and postprocessor may very likely incorporate memories of their own. The buffer (which can also act as data counter) produces data in serial form.



ORIGINAL PAGE IS OF POOR QUALITY

Fig. 1. Simplified data-flow block diagram of advanced-design ADC

C. CANDIDATE FEATURES AND CAPABILITIES OF AN ADVANCED-DESIGN ADC

The following are prime examples of ADC programmability features and capabilities of the type that could be provided by the incorporation of a pre- or post-processor. Before proceding with the explanations of individual features,however,it appears useful to describe some typical characteristics of a sensor-output signal, to define such features as gain selection, range selection and zero suppression, and to explain the usefulness of certain other potential ADC features.

Figure 2 illustrates a fictitious sensor-output signal, purposely constructed to bring out certain characteristics although it is unlikely that all of these characteristics may appear in the output of one sensor. The curve shows a slow variation in amplitude in the lowest portion of the output span. When useful information is contained in this portion of the range, gain selection can be applied to amplify the signal and thus enhance the information presented by it. Next, the curve shows a high-frequency phenomenon, a rapid fluctuation of the measurand. In some cases this phenomenon does not represent useful information. Filtering can then be applied to smoothen the input to the ADC. On the other hand, such rapid fluctuations may present important information. In this case, the ADC sampling rate, and possibly also the conversion speed, can be increased to enhance the information. The curve then rises to a peak and drops to a "valley". Only one of each are illustrated; however, some signals are characterized by many such peaks and valleys, often occurring in rapid succession. In some cases, only the highest of these peaks, or the lowest of the valleys, present essential information. Provisions can then be incorporated to find, and convert, only the highest peak, or the lowest of the valleys, and suppress all other information. Next, the signal shows gradual amplitude variations in the upper portion of the output range. Zero suppression can then be applied to enhance this information. The "zero" of the ADC is artificially shifted to a value near the upper end of the output range (e.g., 4 V, in this illustration), such as by applying a reference bias voltage, and amplification is used to increase the one volt difference between 4 and 5 volts so that it equals the full-scale input required by the ADC. Finally, the signal is seen to vary in a narrow portion of the output range (between 2.5 and 3.5 V, in the illustration). Range selection can then be applied to suppress any information below 2.5 V and above 3.5 V and amplify the one volt difference so that it equals the full-scale input of the ADC.

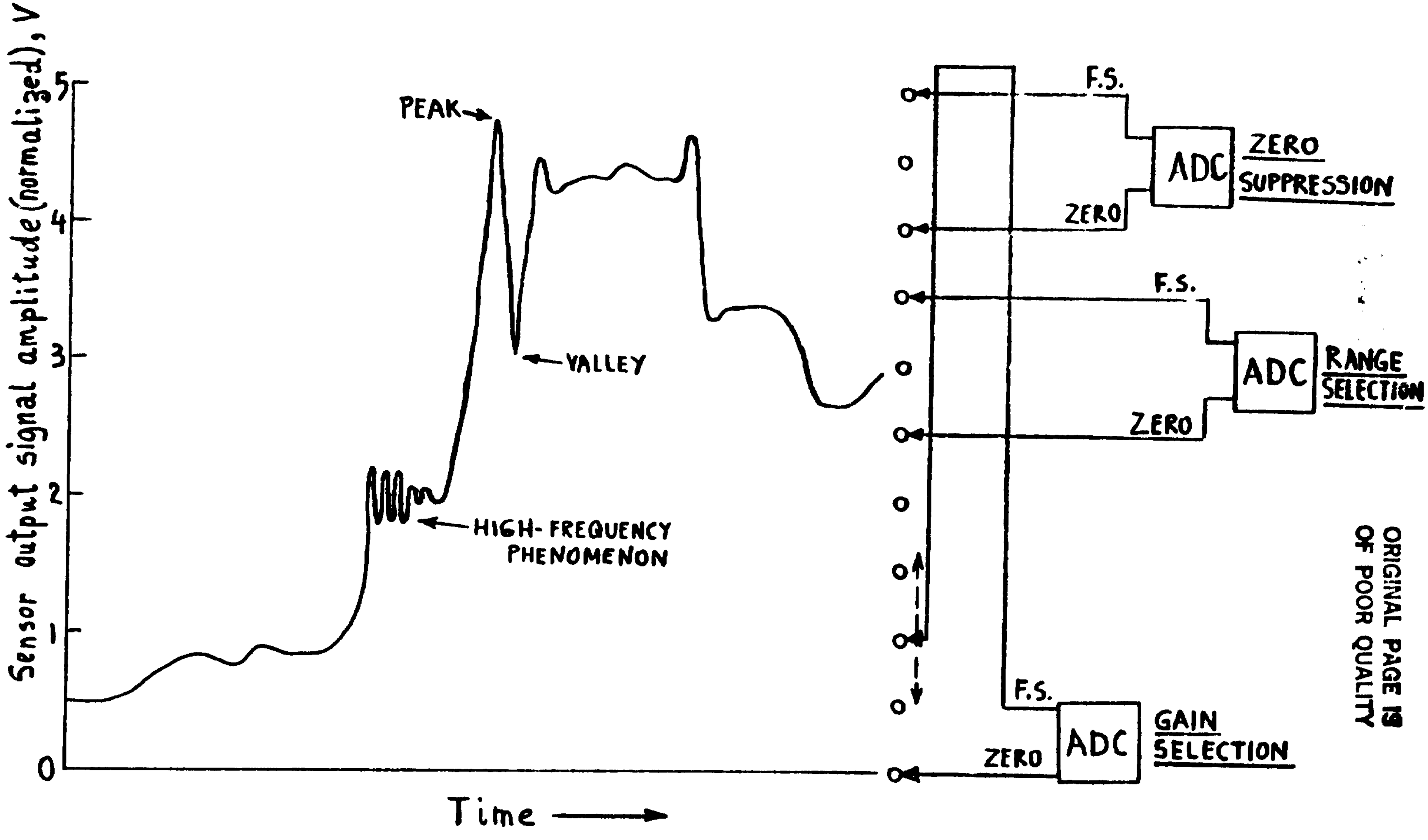


Fig. 2. Examples of sensor output-signal characteristics and range expansion methods (Note: F.S. = full-scale input signal to ADC)

1. Programmable Gain (Gain Selection)

ADC gain programmability adjusts the full-scale analog input range required to provide a full-scale digital output. The ADC then amplifies weak signal levels and could also reduce high signal levels in excess of a normalized output-signal range. Gain changes occur in discrete steps, and status information from the ADC indicates the gain level in force. The gain changes would best be provided in an adaptive mode, but could also be externally commandable.

Benefits: It is primarily the adaptive amplification of weak signals carrying useful information that can enhance science return and improve pointing control (when,e.g., the target brightness is reduced). Spacecraft autonomy and diagnostics would be facilitated by the increased flexibility provided by programmable ADC gain. One example of the latter is the increased visibility obtainable when certain spacecraft parameters tend to be in the very low portion of their full-scale range.

2. Programmable Zero Suppression

Zero suppression is very useful when a signal is in a region near its upper range limit and is expected to remain there for some period of time. By means of, typically, a reference bias voltage the zero input level of the ADC is artificially shifted to a level corresponding to somewhere between 75 % and 90 % of the nominal sensor output-signal range. The difference between that level and the full-scale sensor output level is then amplified to correspond to the full-scale input range of the ADC. This results in a much finer resolution for signals in that limited portion fo the range. Zero suppression can be introduced in one or more steps (e.g.,"zero"= 80 %, or"zero"= 70, 80, or 90 %). The ADC outputs status information to show the suppression level in force. Zero suppression can be adaptive, but is more likely to be implemented as externally programmable.

Benefits: Zero suppression can enhance science return by providing finer resolution for "high"-range signals; such finer resolution can also help to improve pointing control. There is also a potential for hardware cost reduction, when continous-resolution transducers (e.g., actuator-position transducers are used with a programmable-zero-suppression ADC in lieu of a pair of coarse/fine transducers.

3. Programmable Range Selection

Programmable range selection provides mid-range expansion. Zero suppression is used to shift the ADC "zero" input level to some mid-range point, say 40 % of the nominal sensor output-signal range. Additionally, upper-limit suppression is implemented to limit the signal range to a lower level, say 60 %. The difference between these levels is then amplified so that the ADC produces full-scale digital output for signal variations between 40 and 60 % of the nomonal sensor output span..Range selection could be provided in several preselected steps (say 20 -30 %, 30 - 40 %, 40 - 50 %, etc., or 20 - 40 %; 40 - 60 %, and 60 - 80 %), with ADC status information showing the range selected; it is more likely to be implemented as externally programmable, but could be handled in an adaptive mode. Range selection provides primarily finer resolution for signals that remain in their mid-range for periods of time. Benefits: Range selection can enhance science return by providing finer resolution for mid-range signals. The increased flexibility enabled by providing such finer resolution also aids spacecraft autonomy and diagnostics. Cost savings may be possible by replacing a coarse/fine pair of transducers by a single transducer.

4. Programmable Filtering

Programmable filtering smoothens unwanted high-frequency phenomena in the output signal and reduces errors that could be caused when a peak of the high-frequency phenomenon is inadvertently sampled. The implementation is similar to inserting one of a family of low-pass filters,with specified high-frequency cut-offs, into the input side of the ADC. An adaptive mode would be preferred for programmable filtering; alternatively, it could be externally selectable, depending on the predictability of the occurrance of unwanted high-frequency phenomena. Benefits: By reducing errors in data words due to inadvertent sampling of a peak of an unwanted high-frequency phenomenon in a sensor output signal (i.e., the information presented by the high-frequency fluctuation or transient is not useful information) erroneous actions in spacecraft autonomy and diagnostics systems can be prevented. Similarily,such error prevention simplifies ground operations by reducing the possibility of "false alarms".

5. <u>Programmable Sampling Rate</u>

Programmable sampling rates are very useful when a sensor output signal varies slowly during some mission phases or events and fluctuates rapidly during other mission phases or events, provided that such rapid fluctuations furnish useful information. The ADC would be capable of adjusting the rate at which it samples and converts the signal, either adaptively or, more probably, by external commands, with status information indicating the sampling rate (e.g., one every 10, 100 ms, 1 s, 10 s, etc.). The output buffer of the ADC can be sized for holding an expected maximum of data words generated at high sampling rates and the data system could adjust the sampling rates of other sensors so that the total data volume and/or rate remains the same.

<u>Benefits:</u> Science return can be enhanced by providing more precise information about rapid fluctuations in the signal, when such fluctuations contain useful information. Pointing control can be improved if the sampling rate can be adjusted,e.g., for a target sensor when the relative target-spacecraft motion is highly variable. The increased flexibility in data acquisition also aids on-board autonomy and diagnostics.

6. <u>Programmable Conversion Speed</u>

Programmable conversion speed may be a required adjunct to sampling rate programmability when signal sampling and conversion needs to be at very fast rates.

<u>Benefits:</u> Same as for programmable sampling rate, except that signal variations that require such extra-fast conversion speeds are not expected to be of significance to spacecraft autonomy or diagnostics.

7. <u>Programmable Encoding/Data Word Length</u>

The encoding of analog signals for any one given sensor and resulting data word lengths (e.g., 8 bits, 12 bits) have customarily been fixed for a given spacecraft system and mission. Fixed data word length are also more or less a firm requirement when time-division-multiplex telemetry is used. The relatively recent introduction of packet telemetry, however, enables significant benefits to be gained by making the encoding variable and programmable. The data word length in a source packet can be different for different packets, with the packet header indicating the length of the data words.

Programmable ADC encoding changes are probably best controlled by a central element in the spacecraft data system. It should be noted that encoding affects only the resolution of the digital signal over the full range of analog signal presented to the ADC.

The primary application envisioned is to data emanating from each of a group of science instruments since it is these sensors that produce the highest data volume during a mission. Programmable encoding can do the following:

a. Reduce the overall downlink data rate when coarse resolution in one or more instrument outputs is acceptable.
b. Maintain a uniform downlink data rate when it is desirable to increase the sampling rate within instruments at the cost of lower resolution in their data.
c. Maintain a uniform downlink data rate when finer resolution is needed for one or more instruments at a time when coarser resolution can be accepted for one or more other instruments.

Typical Control Algorithms:

There are several different generalized control algorithms which could be used to change analog-signal encoding: the following should serve as examples:

a. Pre-set Changes:

(1) Mission-time-initiated: For a given sensor, change the encoding (e.g., from 12 bits to 8 bits) at specified times during the mission, then reverse the change.
(2) Event-initiated: Whenever a specified event occurs, change the encoding for one or more specified sensors to a specified data word length, and for a specified period of time, then reverse the change.

b. Adaptive Changes:
The intent of the following examples is to maintain a constant data volume and constant downlink data rate.
(1) When Instrument A produces data faster than a predetermined rate, encoding is reduced for Instrument A proportionally to the data rate (in discrete increments).
(2) When Instrument A produces data faster than at a predetermined rate, reduce the encoding for Instrument B (or for Instruments B,C, D...,n) in accordance with a stored (but programmable) priority protocol.
(3) When two or more instruments produce data at a rate faster than a predetermined rate, reduce the encoding for one or more other instruments in accordance with a stored (but programmable) priority protocol.

ORIGINAL PAGE IS
OF POOR QUALITY

Benefits:

Science return is enhanced because science instruments need no longer be turned off (or data acquisition by them stopped) during certain mission phases or events,- they just provide data with coarser digital resolution. Instruments which observe more phenomena than expected at a given time get priority for data acquisition.
Holding down the downlink data rate reduces spacecraft system cost since it reduces the need for larger numbers of data modes and rates, reduces the need for higher-power radio transmitters or larger antennas on the spacecraft to accomodate extra-high data rates, and reduces the need for a larger power source (for a higher-power transmitter) or finer pointing control (for a larger antenna).
Spacecraft autonomy and diagnostics can be facilitated by programmable encoding which improves system flexibility by allowing the encoding of individual transducer outputs to be controlled in an optimum manner.
Testing is simplified due to the reduction in the number of data modes and rates.

Whereas the above features and capabilities are envisioned as being provided by enhanced ADC programmability, the candidate features explained below would require some sort of either analog preprocessor or digital postprocessor to be incorporated into the ADC. For some capabilities, e.g., high-speed peak/valley search,an analog preprocessor seems preferable, for others a digital postprocessor may be more suitable.

8. Engineering-Unit (EU) Conversion per Stored Calibration

The "calibration" of a sensor is a (graphical or tabular) representation of the sensor's output-vs-measurand relationship (transfer function). This relationship can be inherently linear or nonlinear. Each sensor is calibrated on the ground and its calibration is established. EU conversion of digital data is customarily performed on the ground by programs which operate on the data and convert "digital numbers"(DN's) to EU's (e.g., 106 DN = 46.8 °C) on the basis of the calibration established for the sensor and using typivally a curve-fitting process that involves up to 5th order polynomials.

Processing within an ADC could be used to, initially, linearize and normalize the calibration of each sensor. Additionally, the calibration could be stored and the signal or data could be processed within the ADC so that the serial output data represent the measurand in appropriate EU's.
A limitation on such an on-board capability is given by the preference for 8-bit engineering data words; this would limit engineering units to number between 0 and

ORIGINAL PAGE IS OF POOR QUALITY

255. Additional difficulties arise when polarity must be indicated (e.g., minues 50 °C, plus 78 °C). Further, the ground processing system (and any on-board autonomy or diagnostics system) must always know the unit in which a given measurement is expressed (e.g., mV, °C, N, psia or kPa).

Benefits:

On-board autonomy and diagnostics would be facilitated by linearization and normalization and may possibly benefit from EU conversion.
Ground operations and testing would be simplified, and ground costs reduced, by having this processing done on the spacecraft.

9. Compensation for Calibration Shifts

Sensor calibrations are established on the ground, under controlled conditions. Qualification and some types of acceptance tests also establish typical calibration shifts due to, e.g., elevated or low operating temperatures. Long-term drifts and shifts, however, cannot be established on the ground. Such shifts can (and often do, to varying extents) occur in the sensing element itself (e.g., thermistor, pressure-sensing diaphragm) or in the electronics immediately associated with the transduction element (e.g., preamplifier, resistance bridge, demodulator).

Such shifts can be corrected for by adding the capability of periodically switching in a calibration reference, then, if the sensor calibration is stored in the ADC preprocessor, correcting the calibration for shifts observed. If on-board calibration storage and EU conversion is not implemented, the shift compensation feature can still be useful if ground processing can accept information about such shifts and then cause the EU conversion to be suitable corrected.

When such shifts are expected to occur primarily in the sensor electronics, the ADC controller can control switching the electronics from the raw sensing-element-induced signal to an artificial reference signal corresponding to a known point on the output-vs-measurand relationship. If two levels of reference signal are used, the zero and slope changes of the calibration curve can be fairly well established. When shifts are expected to occur primarily in the sensing element, a more complex reference source is required,e.g., a source of accurately controlled pressures and a pneumatic or hydraulic switch plumbed to the inlet port of the pressure transducer.

ORIGINAL PAGE IS OF POOR QUALITY

Benefits: Calibration shift compensation based on on-board references would facilitate spacecraft autonomy and diagnostics by providing a truer knowledge about the measurand. Ground operations and testing would be simplified by obviating the need to correct data for shifts that can, at any rate, usually only be inferred from other information. Pointing control would be improved by correcting the assumed transfer function of a sensor to the actual transfer function.

10. Data Suppression

The value of data suppression is given by one of the most important dictates of dat system optimization: send only meaningful information through the system.Data suppression, as described in the examples below, is intended primarily for engineering and probably also science housekeeping data; however, it may apply to some science data, at times, as well. The following are typical examples of data suppression:

a. Amplitude-governed Data Suppression:

A band of "normal" (or "nominal") values, or a single set-point,is established for a given sensor output signal If the signal remains within this band, or if it is above or below the set-point, the data are not sent; instead, the ADC sends status information ("OK" or "GREEN") to the spacecraft data system. The band limits or set-point must be reprogrammable in most cases since they are often different for different mission phases or events.

If this type of data suppression is implemented by the ADC preprocessor, any "OK" signals are simply not encoded; only status is sent. If, on the other hand, it is implemented in the digital postprocessor the method used would be very similar to that applied to "alarm limits" in ground data displays.

In the case of engineering and housekeeping sensors it is usually a band of amplitudes that is specified. An advanced-technology data system is envisioned in which each sensor is equipped with an ADC that provides this capability. As long as signals stay within their nominal-amplitude bands, a "healthy" status is indicated. When the signal goes outside the band, some problem or unhealthy trend is indicated.

In the case of science sensors, a set-point could be specified just above the "noise" level. Alternatively, it could be set at a somewhat higher level if information represented by amplitudes below that level is not considered useful. Such an implementation is essentially identical to zero suppression.

b. Amplitude-change-governed Data Suppression

Some measurements are characterized as indicating a "healthy" status when the signal amplitude changes very little, and as indicating an "unhealthy" status when the amplitude changes become larger; the absolute value of the amplitude, however, may be anywhere within a lrage range of amplitudes.
In such cases the ADC preprocessor or postprocessor compares the variations in amplitude to a speciafied (and reprogrammable) variation. The magnitude of a given sample is compared with the magnitude of the previous sample and the new sample is not encoded (if done in the preprocessor) or not sent (if done in the postprocessor) unless the change from the previous sample is larger than the allowable change; instead, status information ("OK") is sent to the data system. If a preprocessor is used for this (or for some of the other data suppression modes explained below) some sort of sample-and-hold feature is probably required in it.

c. Rate-governed Data Suppression

This method can be sued when it is the time rate of change of the sensor output signal amplitude that indicates healthy or unhealthy status. The amplitude of a new sample is compared to n previous samples that were all taken at equal time intervals. If the comparison shows a change of amplitude greater than "x per unit time" the signal is encoded (if this is done in a preprocessor equipped with sample-and-hold and a buffer) or sent (if it is implemented in a postprocessor). Otherwise, only an "OK" status is sent to the data system.

Benefits: Data suppression can provide significant reductions in downlink data transmissions. Ground operations and testing can be simplified and ground costs reduced concmmittantly. On-board data suppression enables the implementation of a "beacon mode" for telemetry, in which a simple low-rate bit pattern is used to indicate a "GREEN" status (all signals are within allowable limits) or an "AMBER" status (one or more signals have exceeded allowable limits). Further, on-board autonomy and diagnostics are greatly simplified. An indication of "out of limits", together with the actual data, greatly facilitates failure sensing which, in turn, can lead to failure isolation and commanded reconfiguration. When such autonomy is implemented on the spacecraft, an additional beacon mode can be implemented: the bit pattern in the downlink data transmission is changed to "RED" which would indicate that a failure-caused reconfiguration has been implemented.

11. Data Averaging

For some measurements it is only important that the average value of the signal, over a specified period of time (which can be seconds, minutes, hours, or days) be known. Data averaging is probably easier to implement in a postprocessor than a preprocessor. Successive values of the signal would be accumulated over the specified period of time, the average would be calculated in a specified form (e.g., rms, mean, mean and standard deviation),and this information would then be sent to the data system.

Benefits: In cases where an average value of a signal provides the most useful (or the only useful) information, averaging can be applied to science data and enhance the information presented in them. However, there are probably far more instances when averaging is applied to engineering data. In both cases, the data volume would be reduced. When applied to engineering data, averaging can also facilitate on-board autonomy and diagnostics, simplify ground operations and reduce ground costs, and simplify testing.

12. High-Speed Peak/Valley Search

Some measurements are characterized by rapid fluctuations in amplitude that include only one peak (or valley) that represents the information that is really desired. Typical examples of this can be found in spectral scans. Rather than using a very high sampling rate and sending all data to the ground, "peak picker" (or "valley picker") circuitry can be used to "catch" the one peak (or valley) that is of significance. This would probably best be implemented in a preprocessor.

Benefits: Science return is enhanced when the true peak (or valley) can be determined; even at fairly high sampling rates such phenomena can easily be obscured and the "real" peak (or valley) must be reconstructed on the ground by inference. Similar on-board determinations can also benefit pointing control. When this method is applied to enginnering sensors (in which case the sampling rate can be much slower and minimum/maximum determinations could also be handled by a postprocessor) the resulting increase in the flexibility of data acquisition can aid on-board autonomy and diagnostics. In all cases, data volume is reduced (if non-useful information is suppressed), ground operations and testing are simplified, and ground costs (for data reduction and analysis) are reduced.

ORIGINAL PAGE IS
OF POOR QUALITY

13. Mathematical Operations

This is the sole example cited here for ADC postprocessor capabilities that involves interaction with data from one or more other sensors. The postprocessor of a given ADC must then be capable of accepting data from one or more other ADC's. It performs mathematical operations on the two or more sensor data, with or without inclusion in the calculation of stored constants, in order to provide information about the parameter that would be the most useful information needed on the ground, or by an on-board autonomy or diagnostics system.

A simple example is electrical dc power, the product of voltage and current. Another example is attitude-control gas mass, derived from pressure and temperature (measured) and density and tank geometry (known). More complex operations could be developed that may,ultimately, convert science sensor signals into the form in which it can most easiily and meaningfully be used on the ground, or in which it can most readily be accepted by an on-board instrument-autonomy system.

Related to multi-sensor data manipulation is sensor-peculiar processing where mathematical operations, analog or, more likely, digital,are used for signal conversion, e.g., integration,differentiation, square-root extraction, logarithmic conversion, exponents, etc.,again with or without the inclusion of one or more pre-stored constants.

Benefits: The capability of an ADC to perform mathematical operations either on the signal of its associated sensor or on that signal in conjunction with data from one or more other sensors can effect substantial reductions in spacecraft data volume, in ground operations and costs, and in test operations. It cna also facilitate on-board autonomy and diagnostics and, by moving processing from a central pointing-control-system processor/memory to the sensor, improve pointing control.

14. Model Comparison:

A mathematical model of the variations, as a function of time, of a signal can be developed and then stored in the pre- or post-processor associated with an ADC. In a typical application the model is in envelope form. The processor then compares the signal variations,over a specified period of time, with the model envelope. This can be used for data suppression: as long as the sensor signal variations remain within the model envelope no data are sent, only an "OK" status indication is given. When the signal variations go outside the envelope only the variance from the model may be needed in some cases; this is a form of data compression.

ORIGINAL PAGE IS
OF POOR QUALITY

In some other cases exactly the opposite is done: the model envelope establishes the information that is desired; data are only sent when the signal variations are within the model envelope.

There are many useful applications of such model-comparison processing. One example is in spectroscopy, when only one spectral line is of importance. A model of a spectral scan, which includes an envelope around the line of interest, is stored. Signals are then not encoded unless the desired line is observed. Another example is given for engineering measurements. Rotatory devices (e.g., a scan actuator) have bearings and rotary motion produces a vibrational "signature" that can be represented by a power spectral density plot. The output of a vibration transducer is fed to the preprocessor which scans frequency vs amplitude and creates a power spectral density plot; the latter is compared to a model representing "normal" bearing operation ("normal" vibrational signature). Data are sent when the model is exceeded.
The latter example shows that an important tool for diagnostics and autonomy,- vibration analysis,- can be used on spacecraft after all; vibration measurements have rarely been telemetered in the past since the frequency band of vibrations required too much bandwidth of the telemetry system. Conversion of the vibration signals into a power spectral density plot does have some amount of history in space vehicle applications; it greatly reduces the bandwidth (data rate) needed to telemeter the essential information. When a model-comparison scheme is additionally introduced, the data rate requirement for needed information ("abnormal" signatures) is reduced to a negligible level.

Benefits: Model comparisons can be a very useful tool for spacecraft autonomy and diagnostics; a major use is forseen in trend analysis. The associated data suppression or compression reduces data volume and rates. Ground operations and costs can be reduced and testing can be simplified.

ORIGINAL PAGE IS
OF POOR QUALITY

15. ADC Self-Compensation for Drift

One of the questions to be addressed as part of this study was "allowable post-radiation drift" of and ADC. Drifts can occur in an ADC due to radiation exposure as well as due to aging. It appears that it would be simple enough to incorporate drift compensation into the ADC so that establishing tolerances for drift would not be necessary. Such compensation could be implemented by, e.g., switching the ADC input to two different, precisely-controlled and long-term stable reference voltages and then feeding back any changes to the gain select circuitry so that the original gain is re-established.

Benefits:Science return would be enhanced since errors due to to ADC drift would be eliminated. The same reduction in information error would also improve pointing control and facilitate on-board autonomy and diagnostics. Further, any attempts to infer errors due to ADC drift on the ground would not be required, ans ground operations would thus be simplified and ground costs reduced.

D. ADC ARCHITECTURE

All of the above considerations of cnadidate capabilities and features indicate the desirability of developing a versatile, programmable ADC with a highly capable signal preprocessor and/or postprocessor. Further, the benefits evaluction is based on sensor-dedicated ADC's rather than post-multiplexer ADC's and this concept is consistent with modern data system technology which is moving increasingly toward distributed-processing schemes.

If the implementation of such new-technology ADC's were based on the use of conventional hybrid electronics, the end result could very easily be a significant increase in spacecraft mass, power and cost. Further, it is not clear at this time which advanced-technology features and capabilities would benefit a majority of users and which would benefit only a few. The application of VLSI technology to advanced-design ADC's appears very desirable. Depending on the outcome of an in-depth user needs survey the architecture options appear to be the following:

a. A single "standard" design which is highly capable; such an ADC would fill the needs of many users while representing and overdesign for some users; however, the device could be mass-produced in VLSI form.

b. a "family" of ADC's, each of which provides only a limited number of features and capabilities; the application of VLSI technology appears desirable for this option as well but cost trades and quantity estimates would have to precede any decision

ORIGINAL PAGE IS
OF POOR QUALITY

regarding construction and design choices.

c. Modular extension of capabilities that could be added to a relatively simple "basic" ADC; the basic design could be mass-produced in VLSI form; however, the add-on modules may not necessarily be in that form.

E. POTENTIAL AREAS FOR FURTHER STUDY

The results of this brief study, as described in this report, represent only a qualitative assessment of features and capabilities that appear desirable in advanced-design ADC's and would provide benefits to spacecraft systems.

Hence, one area that seems desrving of further study is a quantitive assessment of those features and capabilities as well as of basic characteristics of such ADC's, such as number of bits (e.g., is a 16-bit encoder needed ?), conversion speed, and long-term stability. This would probably require an extensive survey of user needs.

Another important area to be investigated is technological feasibility. Technology barriers may prevent some of the desirable features and capabilities from being implemented in the foreseeable future.

A combination of the results of user needs and technology investigations may then also lead to the sort of cost trades that must precede any decisions regarding architecture, construction, and detailed specifications for advanced-design ADC's.

APPENDIX B

October 9, 1981

Refer to: 514-B-RLW:mw

Director, P[illegible]t

Singer, Kear[illegible]n
1150 McBride Ave
Little Falls, NJ 07424

Dear Sir:

We, at the Jet Propulsion Laboratory, have been awarded a contract by the military to select a class of Analog to Digital converters (ADC) for widespread use in radiation environments (both military and space). The ADCs we ultimately select can be in the development or drawing board stage at the present time, as the requirements they must meet will be fully defined in systems designed in three to five years from now.

We are particularly interested in pinpointing candidate devices that meet rather high precision requirements (as yet undefined), high bit rates (10 bits and higher) and ADCs which will resist a total ionizing radiation dose of approximately one megarad (10^6) in silicon. Power dissipation, speed and linearity over temperature will also be factors in our selections.

If your company has such a program or technology offering promise along these lines, I would be very interested in making telephone contact with the key technical personnel. If that discussion looks promising, we are prepared to travel at your convenience in order to assist in bringing this project to a mutually beneficial completion.

Please respond by telephoning or writing me at the address indicated below. Also please send me detailed specification sheets and other technical data on your current ADC product line. Please include your name, title and telephone number, should I need additional information.

Yours truly,

R. L. Weesner,
Member Technical Staff
Mail Station T-1180
(213) 354-7609

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX C

DOMESTIC ADC MANUFACTURERS

COMPANY	ADDRESS	CITY	STATE
A.D. Data Systems	200 Commerce Dr.	Rochester	NY 14623
ADAC	70 Tower Office Pk	Woburn	MA 01801
AND, Inc Stein Associates Div.	770 Hill Road	Waltham	MA 02154
AND, Inc	770 Airport Blvd	Burlingame	CA 94010
Acurex-Autodata	485 Clyde	Mountain View	CA 94042
Advanced Micro Devices	Box 453	Sunnyvale	CA 94086
Advanced Microcomputers	3340 Scott Blvd	Santa Clara	CA 95051
American Microsystems Inc.	3800 Homestead Rd.	Santa Clara	CA 95051
Amperex Electronic Corp. Slatersville Div.	Providence Pike	Slatersville	RI 02876
Anadex	9825 De Soto	Chatsworth	CA 91311
Analog Devices Inc	P.O. Box 280	Norwood	MA 02062
Analog Systems, Div. J. R. Conwell Corp.	P. O. Box 35879	Tucson	AZ 85740
Analogic Corp	1G Audubon Rd	Wakefield	MA 01880
Andromeda Systems	9000 Eton Ave	Canoga Park	CA 91304
Androtek/dmi	Box 29098	Columbus	OH 43229

ORIGINAL PAGE IS
OF POOR QUALITY

DOMESTIC ADC MANUFACTURERS

Applied Systems	26401 Harper Ave	St. Clair Shore	MI 48081
Astrosystems	6 Nevada Dr.	Lake Success	NY 11042
Autonetics	314 E. Live Oak	Arcadia	CA 91006
Avtron Mfg	10409 Meech Ave	Cleveland	OH 44105
Aydin Monitor Systems	502 Office Center Dr.	Ft. Washington	PA 19034
Aydin Vector Div.	Box 328	Newtown	PA 18904
BBK, Inc	75 Travis Ave	Binghamton	NY 13904
BEI Elctrns. Digital Products Division	1101 McAlmont St.	Little Rock	AR 72203
BEI Electronics Industrial Encoder Div.	7230 Hollister Ave	Goleta	CA 93117
BEI Electronics Position Contrls Div.	819 Reddick Ave	Santa Barbara	CA 93103
Bailey Controls Co	29801 Euclid AVe	Wickliffe	OH 44902
Barber Coleman Co. Indl. Instrs. Div.	1750 Rock St.	Rockford	IL 61101
Bay Laboratories Inc.	20160 Center Ridge Rd.	Cleveland	OH 44116
Beckman Instruments, Inc	350 N. Hayden Rd.	Scottsdale	AZ 85257
Beckman Instruments, Inc	2500 Harbor Blvd	Fullerton	CA 92634
Burr-Brown Research Corp.	P. O. Box 11400	Tucson	AZ 85734
Cambridge Thermionic	445 Concord Ave	Cambridge	MA 02138
Canberra Ind	45 Gracey Ave.	Meriden	CT 06450
Cermetek, Inc.	660 National Ave.	Mountain View	CA 94043
Cherry Semiconductor Corp.	99 Blad Hill Rd.	Cranston	RI 02920
Circuit Technology	160 Smith St	Farmingale	NY 11735

ORIGINAL PAGE IS
OF POOR QUALITY

DOMESTIC ADC MANUFACTURERS

Colorado Video, Inc	Box 928	Boulder	CO 80306
Computer Conversions	6 Dunton St.	E. Northport	NY 11731
Consolidated Controls	15 Durant AVe	Berhel	CT 06801
Control Logic	9 Tech. Circle	Natick	MA 01760
Control Module	380 Enfield St.	Enfield	CT 06082
Control Technology Co.	41-16 29th St.	Long Island	NY 11101
Cromemco, Inc	280 Bernardo Ave.	Mountain View	CA 94043
Data Tech of Penril Corp	3110 W. Segerstrom	Santa Ana	CA 92704
Data General	4400 Computer Dr.	Westboro	MA 01581
Data Translation	100 Locke Dr.	Marlboro	MA 01752
Datawest	7333 E. Helm Dr.	Scottsdale	AZ 85260
Datel-Intersil, Inc.	11 Cabot Blvd. Mansfield Indus.Park	Mansfield	MA 02048
Datron Instruments	23011 Moulton-Pkwy-810	Laguna Hills	CA 92653
Datum, Storage Products	1363 State College Blvd	Anaheim	CA 92806
Digital Equipment	One Iron Way	Marlborough	MA 01752
Dionics, Inc	65 Rushmore St.	Westbury	NY 11590
Discon Inductries, Inc.	61 SW 5th Ct.	Pompano Beach	FL 33060
Dynamic Measurements Corp.	6 Lowell Ave.	Winchester	MA 01890
EMM/SESCO	20630 Plummer St.	Chatsworth	CA 91311
EMR Data Systems Div. Sangamo-Weston	Box 3041	Sarasota	FL 33578

DOMESTIC ADC MANUFACTURERS

Electrol Compnay	321 Dewey St.	York	PA 17405
Energy Conversion Devices, Inc.	1675 W. Maple Rd.	Troy	MI 48084
Exar Integrated Systems, Inc.	P. O. Box 62229	Sunnyvale	CA 94086
Fairchild Camera & Instrument Corp. Semiconductor Components	464G Ellis	Mountain View	CA 94042
Ferranti Electric, Inc.	87 Modular Ave	Commack	NY 11725
Fifth Dimension	707 Alexander Rd.	Princton	NJ 0[illegible]
First Computer	825 N. Cass Ave Ste 314	Westmont	IL 60559
GAP Instr.	110 Marcus Blvd	Hauppauge	NY 11787
General Instrument Corp.	600 W. John St.	Hicksville	NY 11082
General Microwave Corp.	155 Marine St.	Farmingdale	NY 11735
Harris Semiconductor	P. O. Box 883	Melbourne	FL 32901
Hewlett-Packard	1501 Page Mill Rd.	Palo Alto	CA 94304
Hughes Aircraft Co Dept G	P. O. Box 90515	Los Angeles	CA 90009
Hughes Aircraft Co Electro Optical & Data Systems	Centinela Ave & Teale St.	Culver City	CA 90230
Hughes Aircraft Co. Microelectronic Systems Div.	2601 Campus Dr.	Irvine	CA 92715
Hybrid Systems Corp	Crosby Dr.	Bedford	MA 01730

DOMESTIC ADC MANUFACTURERS

Hytek Microsystems	16780 Lark Ave	Los Gatos	CA 95030
IBM Instruments Systems	3000 Westchester Ave	White Plains	NY 10604
ILC Data DEvice Corp	105 Wilbur Place	Bohemia	NY 11716
Information Control Corp., Abacus Div.	9610 Bellanca Ave.	Los Angeles	CA 90045
Innovatek Microsystems Inc	Smithfield Rd.	Millerton	NY 12546
Intech	282 Brokaw	Santa Clara	CA 95050
Intel Corp.	3065 Bowers Ave	Santa Clara	CA 95051
Interface Engineering	386 Lindelof Ave	Stoughton	MA 02072
Intersil	10710 N. Tantau	Cupertino	CA 95014
Intronics Inc.	57 Chapel St.	Newton	MA 02158
Jaycor	P. O. Box 85154	San Diego	CA 92138
Kinetic Systems	11 Maryknoll Dr.	Lockport	IL 60441
Leeds & Northrup, Unit of General Signal	Sunnytown Pike	North Wales	PA 19454
Lincoln Instruments	456 W. Montana	Pasadena	CA 91103
Macrodyne	153 Princetown Rd	Schenectady	NY 12301
Measurement Systems, Inc	121 Water St.	Norwalk	CT 06854
Melco Sales, Inc. Mitsubishi Electric Corp Dept G	3030 Victoria St.	Compton	CA 90221
Micro Circuit Engr. Inc.	1111G Fairfield Dr.	W. Palm Beach	FL 33407
Micro Networks Corp.	324 Clark St.	Worcester	MA 01606
Micro Power Systems, Inc.	3100 Alfred St	Santa Clara	CA 95050

DOMESTIC ADC MANUFACTURERS

Midland Standrad Inc.	603 E.Chicago St. Box 38	Elgin	IL 60120
Monolithic Memories, Inc.	1165 E. Arques Ave	Sunnyvale	CA 94086
Mostek Corp.,	1215 W. Crosby Rd.	Carrollton	TX 75006
Motorola Semiconductor Products Inc.	P. O. Box 20912	Phoenix	AZ 85036
NEC Electron Inc	3120G Central Expressway	Santa Clara	CA 95051
NEC Microcomputers Inc.	173G Worcester St.	Wellesley	MA 02181
NES, Inc	1536 Brandy Pkwy	Streamwood	IL 60103
Natel Engr. Co., Inc.	8954 Mason Ave.	Canoga Park	CA 91306
National Semiconductor, Microcircuits Div.	2900 Semiconductor Dr.	Santa Clara	CA 95051
Newport Electronics	630 E. Young St.	Santa Ana	CA 92705
Nitron, Inc	10420 Bubb Rd	Cupertino	CA 95014
North Atlantic Industries	60 Plant Ave	Hauppauge	NY 11787
North Hills Electronics	Alexander Place	Glen Cove	NY 11542
Northern Precision Labs	11 Madison Rd.	Fairfield	NJ 07006
Optical Electronics, Inc	P. O. Box 11140	Tucson	AZ 85734
Perkin-Elmer Corp. Products Dept	Main Ave	Norwalk	CT 06856
Phoenix Data	3384 W. Osborn Rd.	Phoenix	AZ 85017
Phoenix Microsystems	P. O. Box 4206	Huntsville	AL 35802
Precision Monolithics, Inc.	1500 Space Park Dr.	Santa Clara	CA 95050

DOMESTIC ADC MANUFACTURERS

Preston Scientific, Inc.	805 E. Cerritos Ave	Anaheim	CA 92805
Q-Systems	P. O. Box 35879	Tucson	AZ 85740
RCA Corporation, Solid State Div.	Route 202	Somerville	NJ 08876
RFL Inds. Comms. Div.	Powerville Rd	Boonton	NJ 07005
Racal-Dana Instruments	18912 Von Karman Ave	Irvine	CA 92715
Ragen Data Systems, Inc	125 Schmidtt Blvd	Farmingdale	NY 11735
Raytheon So. Semiconductor Div.	350 Ellis St.	Mountain View	CA 94042
Reihl Time Corporation	53 So. Jefferson Rd.	Whippany	NJ 07981
Rochester Instruments Systems	255 N. Union	Rochester	NY 14605
Sanlab	7969 Engineer Road	San Diego	CA 92111
Scientific Measurements	1319 Dobson	Evanston	IL 60202S
Signetics Corporation	811 East Arques Ave	Sunnyvale	CA 94086
Silicon General Inc.	11651 Monarch St.	Garden Grove	CA 92641
Siliconix, Inc.	2201 Laurelwood Rd.	Santa Clara	CA 95054
Singer, Kearfott Div.	1150 McBride Ave	Little Falls	NJ 072424
SolidState Scientific, Inc		Montgomeryville	PA 18936
Solitron Devices, Inc.	8808 Balboa Ave.	San Diego	CA 92123
Sprague Electric Co.	87 Marshall St.	North Adams	MA 01247
Standard Microsystems Ccrp.	35 Marcus Blvd.	Hauppage	NY 11787

DOMESTIC ADC MANUFACTURERS

Superior Mfg. & Instruments	19-36 38th St.	Long Island Cty	NY 11105
Supertex, Inc.	1225 Bordeaux Dr.	Sunnyvale	CA 94086
TRW LSI Products	P.O. Box 1125	Redondo Beach	CA 90278
Tecmar	23414 Greenlawn Ave	Beachwood	OH 44122
Teledyne Semiconductor	1300 Terra Bella Ave	Mountain View	CA 94040
Teledyne Crystalonics	147 Sherman St.	Cambridge	MA 02140
Teledyne Gurley	514 Fulton St.	Troy	NY 12181
Teledyne Philbrick	Allied Drive at Route 128	Dedham	MA 02026
Tennelec	Box D	Oak Ridge	TN 37830
Texas Instruments, Inc. Inquiry Answering Service M/S 308	P. O. Box 225012	Dallas	TX 75265
Theta Instrument Corp.	24 Dwight Place	Fairfield	NJ 07006
Thomson-CSF, Semiconductor Div.	P.O. Box 1454	Canoga Park	CA 91304
Thor Electronics Corp.	321G Pennsylvania Ave	Linden	NJ 07036
Transmagnetics, Inc	210 Adams Blvd	Farmingdale	NY 11735
Tucker Electronics	Box 401060	Garland	TX 75040
Varian Associates	611 Hansen Way	Palo Alto	CA 94303
Veeder-Root	70 Sargeant St.	Hartford	CT 06102
Velonex Display Products	560 Robert Ave	Santa Clara	CA 95050
Western Digital Corp.	P. O. Box 2180	Newport Beach	CA 92663
Wyle Computer Products	3200 Magruder Blvd	Hampton	VA 23666
Xycom	750 N. Maple Rd.	Saline	MI 48176

DOMESTIC ADC MANUFACTURERS

Zeltex Inc.	940 Detroit Ave	Concord	CA 94518

ADC MANUFACTURERS - FOREIGN

COMPANY	ADDRESS
FUJITSU,LTD.APP.ENG.PROD.	1015 KAMIKODANAKA,NAKAHARA-KU,KAWASAKI,211,JAPAN
FERRANTI,LTS ELECTRONICS DEPT.	GEM MILL, CHADDERTON, OLDHAM,LANCS., ENGLAND
HITACHI LTD.	6-2, OHTEMACHI 2-CHROME, CHIYODA-KU,TOKYO 100 JAPAN
ITT SEMICONDUCTORS INTERMETALL	P. O. BOX 840,D-7800,FREIBURG 1 BR, WEST GERMANY
MATSUCHITS ELECTRONICS CORP	1 KOTARI TAKEMACHI, NAGAOKAKYO, KYOTO 617, JAPAN
MITEL SEMICONDUCTOR	BOX 13089, KANATA, OTTAWA, ONTARIO,CANADA K2K 1X3
MITSUBISHI ELECTRIC CORP	4-1 MIZUHARA, ITAMI-SHI, HYOGO-KEN P.C.664,JAPAN
MULLARD LTS. MULLARD HOUSE	TORRINGTON PL, LONDON WC1E 7HD ENGLAND
NIPPON ELEC. ELECTRON DEV.	1753 SHIMONUMAKE, MAKAHARA-KU, KAWASAKI, JAPAN
OKI ELECTRIC INDUSTRY CO. LTD	10-3 SHIBAURA 4-CHROME, MINATO-KU, TOKYO 108 JAP
PHILIPS GLOEILAMPENFABREIKEN	ELCOMA TECH DEPT BLDG BA, EINDHOVEN, NETHERLANDS
PLESSEY SEMICONDUCTOR CHENEY	MANOR, SWINDON, WILTSHIRE, ENGLAND SN2 2QN
R.T.C. LA RADIOTECHNIQUE-COMP.	130 AVE. LEDRU-ROLLIN, 75540, PARIS CEDEX 11 FR.
SEMICDTRS. LTD.M/S ADVANI OERL	IKON LTD. AHMEDNAGAR RD MILE 4/5 POONA 411 014 INDIA
SGS-ATES COMP. ELET. S.P.A.	VIA C OLIVETTI 2 20041 AGRATE BRIANZA, MILAN ITALY.
SIEMENS AKTIENGESELLSCHAFT,	BALANSTRASSE 73, D8000 MUNICH 8 WEST GERMANY
THOMSON-CSF SESCOSEM	50, RUE JEAN PIERRE TIMBAUD, BP5, 92401 COURBEVOIE, FRANCE
TEXAS INSTRUMENTS	MANTON LANE, BEDFORD ENGLAND
TOSHIBA CORP. 1 KOMUKAI,	TOSHIBA-CHO, SAIWAI-KU, KAWASAKI, KANAGAWA 210 Japan
TOKYO SANYO ELEC. CO. SEMICON.	OIZUMIMACHI, ORAGUN, GUMMA, JAPAN
TUNGSRAM	H-1340, BUDAPEST, HUNGARY
VALVO GMBH,	P.O. BOX 993, D2000, HAMBURG 1, WEST GERMANY
BOURNS AG	ZUGERSTRASSE 74G, 6340 BAAR, SWITZERLAND

EFCIS, DEPT G	BP 217, 38019-GRENOBLE CEDEX, FRANCE

ELEKTRONISCHE BAUELEMENTE VERT REIBS GMBH, KONRAD-CELTISSTR 81G,8000 MUNICH 70 WEST GERMANY

INTERSIL DATEL 9TH FLOOR SNAMPROGETTI HOUSE, BASING VIEW,BASINGSTOKE HANTS, ENG

MATSUSHITA ELEC CORP 1-1 SAIWA I-CHO, TAKATSUKI-CITY, OSAKA 569, JAPAN

SILICONIX, LTD. LIANLLIENWEN	CLOSE, MORRISTON, SWANSEA SA6 6NE WALES
THOMSON-CSF, RUE DE COURCELLES	BP 96-08, 75362 PARIS CEDEX 08, FRANCE
HITACHI LTD. 5-1	1-CHROME MARUNOUCHI CHIYODA-KU, TOKYO 100 JAPAN
MITEL SEMICONDUCTOR	18 AIRPORT BLVD. ,BROMONT, QUE JOE 1LO, CANADA

COMPANY RESPONDING	COMMENTS	INTEREST
Analogic	Modules	no
Amperex	Hybrids	no
Raytheon	10-bit flash	yes
Intech		yes
ILC	Hybrids	no
Dynamic Measurements Corp.	Modules	no
AMD		yes
Ferranti	Flash, 12-bit 1982	yes
Circuit Technology, Inc.	Hybrid	no
Western Digital	A/D for telephone	yes
Burr-Brown	Modules	no
Hewlett-Packard		no
Fifth Dimension		no
Tecmar		no
Computer Conversions		no
NEC Electronic		no
Tungsram, Hungary	(Letter returned)	?
Acurex Auto-Data		no
Rochester Instruments		no
Data Translation		no
Teledyne-Crystalonics		no
Datum		no
Supertex		no
Velonex Display Products		no
Cermetek.		no
Tucker Electronics		no
Preston Scientific		no
Autronics		no
Transmagnetics		no
RFL		no
Universal Semiconductor	(Custom wafers)	no
IBM	(Phone response)	no
Natel		no
Intronics		no
Control Module		no
Beckman Instruments	CMOS 12-bit	?
Northern Precision Lab		no
Phoenix Data	Modules	no
Data West		no
Newport Electronics		no
Theta Instrument Corp.		no
Aydin Monitor Systems		no
Dionics, Inc.		no
Consolidated Controls		no
Plessey Semiconductor	2-4 bit only	no
Valvo GMBH, Germany	Refer to TRW	?
RCA	CMOS, flash	yes

COMPANY RESPONDING	COMMENTS	INTEREST
Analog Systems		no
Siliconix	MOS tech	?
Westech		no
Analog Devices	10-bit - 12-bit I^2L	yes
Siemens	Flash 6-bit	yes
Honeywell Controls		?
Canberra		no
Zeltex		no
Hytek Microsystems		no
57 companies		8 yes
		5 ?
		44 no
		57 total

FOLLOW UPS

#1:

RCA
Ferranti
Analog Devices
Siemens
Honeywell
TRW
Texas Instruments
Raytheon
Intech

9 companies

#2:

Teledyne-Philbrick
Datec-Intersil
AMD
Advanced Microcomputers
Harris
Hughes Microelectronics
Intersil
Motorola
Mostec
National
PMI
Signetics
Western Digital
NEC
Beckman Instruments

15 companies