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Wind Turbine Data Acquisition and Analysis System

Bernard Stiefeld

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department
of Energy under Contract AT(29-1)-789

Printed July 1978

Sandia Laboratories

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Printed in the United States of America

Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy \$4.50; Microfiche \$3.00

SAND77-1164
Unlimited Release
Printed July 1978

Distribution
Category UC-60

WIND TURBINE DATA ACQUISITION AND ANALYSIS SYSTEM

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ABSTRACT

Under Department of Energy (DOE) sponsorship, Sandia Laboratories has implemented a program to develop vertical-axis wind turbine (VAWT) systems. One aspect of this program has been the development of an instrumented test site adjacent to Sandia Laboratories' Technical Area I on Kirtland Air Force Base. Three VAWTs are now in operation on this test site. This paper describes the data acquisition and analyses system developed to meet the needs of the VAWT test site. The system employs a 16-bit work-length mini-computer as the major element in a stand-alone configuration. A variety of peripheral devices perform the required data acquisition functions and provide for data display and analysis. Included is a disk-based software operating system that supports a mass storage-file system, high-level language, and auxiliary software procedures.

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WIND TURBINE DATA ACQUISITION AND ANALYSIS SYSTEM

Introduction

Objectives

The objective of this program was to develop an instrumented outdoor wind laboratory to evaluate various aspects of wind turbine performance and support general site-oriented wind studies. Instrumentation and supporting software developed for this laboratory can be applied to the evaluation of any type wind turbine or various other devices that may or may not be related to the wind program. The specific purpose of this outdoor laboratory and its instrumentation, however, is to evaluate VAWT prototype units developed as part of Sandia's wind-energy program.

VAWT Characteristics and a General Background of Wind-Power Studies

Descriptions of VAWT characteristics and a general background on the subject of wind power can be obtained by reviewing References 1, 2, and 3. At Sandia, we have erected three wind turbines: 2-m, 5-m, and 17-m machines. The 17-m machine has been outfitted with the greatest number of transducers, and its instrumentation is described in some detail.

In evaluating the performance of the 17-m VAWT, we have concentrated on two areas:

1. Structural aspects of turbine operation, primarily blade performance, including vibratory response characteristics.^{4, 5}
2. Performance characteristics of torque output vs wind velocity and related studies of system power losses and electrical output characteristics.^{6, 7}

Major factors considered in wind studies are determination of wind-velocity history, gust-related frequency parameters, and terrain-related wind-shear factors. (Wind shear is evidenced by velocity difference with altitude of ~ 0 to 45 m [0 to 150 ft] above the surface.) This factor is important in evaluating turbine efficiency as it is applied to find the wind velocity at the turbine equator. It should be noted that the power available in a moving fluid stream is proportional to the cube of the velocity; an accurate determination of wind velocity is therefore needed for calculation of performance factors.

Criteria for Design of a Wind-Turbine Data Acquisition and Analysis System for Sandia

In designing a data acquisition system, consideration is usually given to traditional physical parameters such as number of channels, required sampling rates, voltage levels, noise sources, etc. However, in developing a system for use in the laboratory environment that exists at Sandia, consideration should be given to other more subtle factors. Among these are

1. background and training of principal users of the system,
2. desired end use of the data,
3. desired or required speed of data analysis wanted and complexity of analysis,
4. propensity to modify system requirements for either hardware or software.

The ultimate usefulness and longevity of a laboratory-located system may depend as much on proper evaluation of these four considerations as on any traditional factors. In this instance, the users of the equipment and data were essentially the same group of Sandia staff members, all highly trained and intimately involved with both operational and analytic phases of the Sandia wind-energy program. Many of these staff members are well versed in use of FORTRAN and time-share terminal operations, but none are familiar with detailed computer operations, and none have training at the assembly-language level. Discussions with these staff members indicated strong requirements for a flexible software and hardware system. The staff agreed that initial operational data acquisition should use the "method of BINS"^{6, 7} (a summary of "method of BINS" is contained in Reference 7), but much uncertainty existed about probable future testing after the initial evaluations. A capability for general wind characteristic studies was also desired.

Blade and cable tiedown systems for dynamic and steady-state conditions^{4, 5} were analyzed. Based on data from studies, we made decisions about sampling rates, blade strain-gage locations, and transducer/voltage response.

For technical personnel trained in their own specialties but with little experience in assembly language, computer programming, and interfacing instruments, the hardware/software problems can be formidable. To overcome this hurdle, the following four guides were established for procuring the control system and related instrumentation:

1. To facilitate software development and future software expansion, the system will support a high-level language, preferably one generally familiar to Sandia Laboratories personnel. An adequate file system will be available for program storage, modification, and data manipulations. The key element here is the use of a well-known, high-level language.

2. A fast multichannel analog-to-digital (A/D) converter will be the main data-acquisition unit. As a corollary to this decision, transducers and signal conditioning modules will be procured that will provide analog outputs proportional to the input stimulus. The rationale here is that the A/D converter input lines will be brought out of the computer system to a plug connector or strip connection system. Interfacing then involves simply wiring the analog outputs to the A/D input plugs. Additions or modifications are straightforward and generally would require no modifications to the computer input-output (I/O) system. A new transducer could thus be added by personnel with little detailed computer hardware background. For software, a general-purpose A/D call from the high-level language is used so that no assembly language programming effort is required if a new transducer is added to the system.
3. To assure the quality of the data acquired and to speed up data review, the system should be capable of performing real or near real-time data reduction and display. The term "display" here includes a reasonable graphic capability as contrasted to a minimal printing capability.
4. All elements of the computer system should come from one company, one having a good service reputation in the Albuquerque area. This requirement minimizes confusion in pinpointing responsibility when difficulties arise. Dealing with several companies to put a complex system together is almost impossible if technical problems arise.

The major trade-off for these four items is cost. Procurement time is probably reduced because of simplifications from the user's view. Use of a high-level language generally implies supporting software items such as an editor, compiler or interpreter, file management, etc. Convenience and ease of use increases disk speed and capacity requirements, and therefore the cost of the disk system increases over the cost of a minimal assembly-language-based system. The cost of a suitable A/D converter will be greater than that for a minimal system and additional memory to handle files and more complex data reduction programs will be required. Finally, the I/O devices to support graphic output on a fast near real-time basis will cost much more than a simple TTY device or modest speed-line printer device.

Summary

Delivery of hardware elements of the system was made in September through November of 1976. The data system was operational at the VAWT site in January 1977, acquiring data from the 15-m VAWT that was in place. The 17-m VAWT was installed in February and March 1977, with initial testing starting in March. The 2-m machine came into operation in March 1978.

All three machines have been interfaced with the data system with little or no deviation from the original planning. The entire system has exhibited a satisfactory level of reliability with no downtime exceeding 3 days. In approximately 18 months the data system has been down only twice. Strain-gage connections have been the principal hardware problem. Three strain gages out of 21 are now inoperable due to open leads.

Much FORTRAN-based software has now been written for the system. Generally, individual staff members have written their own programs, with at least four staff members having become proficient on the system. Several general wind analysis procedures have been placed on the system, taking advantage of the ease of programming and anemometer interfacing. The graphic capability of the system has been used extensively. This has resulted in not utilizing the magnetic tape system as intended to transfer data to the Sandia central computer system.

At this time, the only significant change to the system planned is the addition of a cassette reader. This reader will read tapes from remote weather stations. Software will be developed to reduce this data to evaluate long-term site wind characteristics.

System Hardware Description

Significant elements of the data acquisition and control system are diagrammed in Figure 1. The system Central Processing Unit (CPU), an HP 21 MX minicomputer 16-bit machine with 32,767 words of core memory, was chosen to meet the four criteria outlined in the previous section. Sandia's facility and digital system design and development had acquired considerable software and hardware experience on a recently installed digital acquisition system.^{8,9} A suitable local service organization was available, and several hardware/software requirements were similar to those for the proposed wind test facility and the recently completed centrifuge digital acquisition and analysis system.

Figure 1. HP 21 MX Computer System Elements

For ease of interfacing and system software utilization, the following items were sole-sourced from the CPU manufacturer at the same time the CPU order was placed.

1. HP 2313 A/D system with 48 channels
2. HP multiprogrammer unit
3. HP 7905 7.2 megaword disk system
4. HP 7970E 9-track high-density magnetic tape system
5. HP relay interface card
6. HP paper tape reader
7. HP card reader

All equipment is mounted in a standard 6-ft tall, double-bay instrument rack. Items 3, 4, 6, and 7 above deal only with the CPU unit. Their service maintenance is a problem for the HP service organization. Items 1, 2, and 5 deal with data signals from the turbines, but it is easy to determine if the turbine signals are present and, if so, whether malfunctions are HP service problems. It is important that the wind group's few instrument people do not spend excessive time dealing with the complex CPU/peripheral interfaces. After initial shakedown, this equipment has been reliable, with little down time. The Tektronix graphics terminal and its hard-copy unit were procured because of relative simplicity in use, availability of software support at Sandia, and lack of competitive options during procurement.

The following information describes specifications for the significant system components.

Pulse Code Modulator (PCM) Encoder, Bit Synchronizer, Decommutator and Interface

The major task of the PCM system is to provide a noise-free way to acquire high- and low-level data from the rotating members of the turbine. Figure 2 is a system diagram of the encoder system. Basically, the encoder takes multiple analog data channels and converts from analog form to a serial digital data stream, adding frame-sequence and word-sequence coding. The bit synchronizer and decommutator located in Building 899 near the CPU decode the serial stream, provide frame pulses, and parallel digital data words to the computer interface unit for acquisition by the computer as determined by appropriate programs. The advantage of the PCM system is that multiple channels (65 in our case) of data are compressed into a single transmission channel containing high-level digital data. This high-level digital stream is largely immune to the usual analog AM noise encountered in slip-ring operation and cable transmission.

Figure 2. PCM Encoder System Diagram

PCM systems typically operate in a continuous-frame-oriented mode, which requires computer memory space for an integer number of frames. In our case, since only about 30 of the 65 data words in a frame are used (to allow for expansion), much memory space would be wasted. To overcome this problem, the Sandia-designed interface between the PCM decommutator and computer passes only a program-specified group of continuous data words from each frame. This hardware/software match maximizes the number of memory words available for data taken with the PCM system. To aid in implementing this feature, high- and low-level channels are intermingled in the data-word sequence so that a continuous group of data words can be set up. Table I details the parameters of the PCM encoder system. The data-word sequence of 65 words (2 sync words are not included) is outlined in Table I, along with the connector designations. We are now using data words 16 to 46, which give a continuous combination of high- and low-level channels.

TABLE I
PCM Encoder System

S - SYNC DATA WORDS

Two Sync Words (S1 and S2) Per Frame

	MSB	LSB
S1-	1 0 1 0 1 1 0 1 0 1	
S2-	0 1 0 0 1 0 1 1 1 0	

A - ANALOG DATA WORDS

Fifteen Analog Words. HI-Level Differential Bipolar

$\pm 5.115V$ Full Scale @ 10.0 MV/Bit

Accuracy: $\pm 0.2\% \pm 1/2$ LSB

± 15.22 MV or $\pm 12 1/2$ LSB

B - ANALOG DATA WORDS

Eighteen Analog Words. Low-Level Differential Bipolar w/o Filter

± 20.46 MV Full Scale @ 40.0 MV/Bit

Accuracy: $\pm 2.2\% \pm 1/2$ LSB Max $\pm 1.5\%$ @ 25°C

± 0.470 MV or ± 12 LSB

C - ANALOG DATA WORDS

Thirty-two Analog Words. Low-Level Differential Bipolar With Filter

± 20.46 MV Full Scale @ 40.0 MV/Bit

Accuracy: $\pm 2.2\% \pm 1/2$ LSB $\pm 1.5\%$ @ 25°C

± 0.470 MV or ± 12 LSB

Filter: 3 db @ 25 Hz Max 6 dB Per Octave Rolloff

EXCITATION VOLTAGE

Sixty Channels @ 10 Volts ± 5 MV into a 350-Ohm Bridge

FRAME STRUCTURE

Bit Rate: 33.5 kHz $\pm 1\%$

Word Rate: 3.35 kHz $\pm 1\%$ (10 Bits Per Word)

Frame Rate: 50 Hz $\pm 1\%$ (67 Words Per Frame)

Temperature Range: -20°C to +60°C

TTL DIGITAL OUTPUTS

1. Biphase L, MEB First Out Differential Line Driver 7830
2. Frame Rate Strobe, One TTL Load Drive
3. Bit Rate Clock, One TTL Load Drive

ADC OUTPUT CODES

$+5.115 \equiv 1 1 1 1 1 1 1 1 1 1$

$+5.105 \equiv 1 1 1 1 1 1 1 1 1 0$

⋮

$+0.005 \equiv 1 0 0 0 0 0 0 0 0 0$

$-0.005 \equiv 0 1 1 1 1 1 1 1 1 1$

⋮

$-5.105 \equiv 0 0 0 0 0 0 0 0 0 1$

$-5.115 \equiv 0 0 0 0 0 0 0 0 0 0$

TABLE I (cont)

ENCODER POWER CONNECTOR J1

<u>PIN</u>	<u>FUNCTION</u>
1	+28V
2	+28V
3	Case Gnd.
4	-28V Return
5	-28V Return

REGULATED OUTPUT POWER CONNECTOR J8

<u>PIN</u>	<u>FUNCTION</u>
1	+28V
2	+28V
3	Case Gnd.
4	-28V
5	-28V

ENCODER OUTPUT CONNECTOR J2

<u>PIN</u>	<u>FUNCTION</u>
1	Output "AND"
2	Output "NAND"
5	Frame Rate*
6	Bit Rate*
7	Gnd.
8	NR2-L*

*Test points only

NOTE: Output taken between Pins 1 and 7

Analog Input Channels

Channel No.	Channel Type*	Connector and Pins	Function	Channel No.	Channel Type*	Connector and Pins	Function
1	A1	J3-62, 61	Unassigned	34	A8	J3-30, 29	17 M-W.D.
2	A2	J3-10, 9	Unassigned	35	A9	J3-38, 37	Torque-Main Shft.
3	A3	J3-36, 35	Unassigned	36	A10	J3-14, 13	Torque-Motor Shft.
4	A4	J3-60, 59	Unassigned	37	B11	J4-12, 11	Strain Gage 104
5	A5	J3-56, 55	Unassigned	38	B12	J4-64, 63	Strain Gage 105
6	B1	J4-62, 61	Unassigned	39	B13	J4-34, 33	Strain Gage 113
7	B2	J4-10, 9	Unassigned	40	B14	J4-58, 57	Strain Gage 114
8	B3	J4-36, 35	Unassigned	41	C17	J5-46, 45	Strain Gage 115
9	B4	J4-60, 59	Unassigned	42	C18	J5-22, 21	Strain Gage 116
10	B5	J4-56, 55	Unassigned	43	C19	J5-20, 19	Strain Gage 117
11	B6	J4-4, 3	Unassigned	44	C20	J5-72, 71	Strain Gage 303
12	B7	J4-6, 5	Unassigned	45	C21	J5-42, 41	Strain Gage 304
13	D0	J4-30, 29	Unassigned	46	C22	J5-66, 65	Strain Gage 301
14	B9	J4-38, 37	Unassigned	47	C23	J5-16, 15	Strain Gage 302
15	B10	J4-14, 13	Unassigned	48	C24	J5-40, 39	Unassigned
16	C1	J5-62, 61	Strain Gage 104	49	C25	J5-24, 25	Unassigned
17	C2	J5-10, 9	Strain Gage 105	50	C26	J5-48, 47	Unassigned
18	C3	J5-36, 35	Strain Gage 101	51	C27	J5-50, 49	Unassigned
19	C4	J5-60, 59	Strain Gage 102	52	C28	J5-74, 73	Unassigned
20	C5	J5-56, 55	Strain Gage 103	53	C29	J5-18, 17	Unassigned
21	C6	J5-4, 3	Strain Gage 106	54	C30	J5-70, 69	Unassigned
22	C7	J5-6, 5	Strain Gage 107	55	C31	J5-68, 67	Unassigned
23	C8	J5-30, 29	Strain Gage 108	56	C32	J5-44, 43	Unassigned
24	C9	J5-38, 37	Strain Gage 109	57	A11	J3-12, 11	Unassigned
25	C10	J5-14, 13	Strain Gage 110	58	A12	J3-64, 65	Unassigned
26	C11	J5-12, 11	Strain Gage 111	59	A13	J3-34, 33	Unassigned
27	C12	J5-64, 63	Strain Gage 112	60	A14	J3-58, 57	Unassigned
28	C13	J5-34, 33	Strain Gage 113	61	A15	J3-8, 7	Unassigned
29	C14	J5-58, 57	Strain Gage 114	62	B15	J4-8, 7	Unassigned
30	C15	J5-8, 7	Unassigned	63	B16	J4-32, 31	Unassigned
31	C16	J5-32, 31	Unassigned	64	B17	J4-46, 45	Unassigned
32	A6	J3-4, 3	Flex. Displ. Gage	65	B18	J4-22, 21	Unassigned
33	A7	J3-6, 5	17 M-W.V.				

*Type A Chns $\pm 5.115V$ FullscaleType B Chns $\pm 20.46MV$ Fullscale w/0 filtersType C Chns $\pm 20.46MV$ Fullscale w/25H2 Low Pass filter

TABLE I (cont)

PCM Excitation Voltage Channels
(60 $\pm$ 10V-Shunt Regulated Channels)
(Grouped in Units of 12)

J6-Connector		J7-Connector		J7-Connector	
Pwr Supply Channel No.	Conn. Pins +, -	Pwr Supply Channel No.	Conn. Pins +, -	Pwr Supply Channel No.	Conn. Pins +, -
49	28, 29	25	2, 3	1	54, 55
50	30, 31	26	4, 5	2	56, 57
51	32, 33	27	6, 7	3	58, 59
52	34, 35	28	8, 9	4	60, 61
53	36, 37	29	10, 11	5	62, 63
54	38, 39	30	12, 13	6	64, 65
55	40, 41	31	14, 15	7	66, 67
56	42, 43	32	16, 17	8	68, 69
57	44, 45	33	18, 19	9	70, 71
58	46, 47	34	20, 21	10	72, 73
59	48, 49	35	22, 23	11	74, 75
60	50, 51	36	24, 25	12	76, 77
On/Off 49-60	53, 52	On/Off 25-36	27, 26	On/Off 1-12	79, 80
37	54, 55	13	28, 29		
38	56, 57	14	30, 31		
39	58, 59	15	32, 33		
40	60, 61	16	34, 35		
41	62, 63	17	36, 37		
42	64, 65	18	38, 39		
43	66, 67	19	40, 41		
44	68, 69	20	42, 43		
45	70, 71	21	44, 45		
46	72, 73	22	46, 47		
47	74, 75	23	48, 49		
48	76, 77	24	50, 51		
On/Off 37-48	79, 78	On/Off 13-24	53, 52		

Another subtle feature of the frame-oriented data sequencing that is useful from a software point of view, is the time segregation effect of framing. At the 50-Hz frame rate, we can consider all the data in one frame as being at the same time point. It is often important to investigate the time relationship between parameters. Very simple software approaches can be used to plot data which is already time-segregated because of the framing action of the PCM encoder. For this reason, high-level analog signals representing wind velocity, wind direction, and torque outputs are passed from the ground through the slip-ring assembly to the PCM encoder.

Strain gages positioned on the blades are designated by a three-digit number,¹⁰ the most significant digit indicating the blade and the lesser digits the gage. One additional feature of this PCM encoder unit is the provision for strain-gage excitation voltage. From the initial planning

stages, it has been assumed that the principal transducers employed on the rotating elements of the VAWT would be strain gages. To accommodate this situation, the box containing the PCM encoder also includes 60 10-V, shunt-regulated excitation channels. These channels are physically contained on five printed circuit cards so that any group of 12 excitation channels can be independently turned on or off. Each channel is self-regulating and is therefore independent of possible faults on any other gage channel. The one restriction typical of shunt regulation units is that if a completely open circuit occurs, the regulator circuits demand more current than the power supply can furnish. This has not been a problem; however, if any group of 12 channels are turned on, a 350-ohm load should be placed across any channels not connected to a gage.

Table I includes the PCM encoder connectors indicating pin designations, PCM channel number, functional use, and general parameters of the encoder. It should be noted that the framing rate is programmed at 50 Hz. This implies that 25 Hz is the maximum frequency that should be digitized. This limitation may be overcome by reprogramming the encoder control unit or (in a limited case) connecting the signal in parallel to two evenly spaced channels to give a greater sampling rate to the signal, a form of supercommutation.

Analog-to-Digital Converter - HP-2313

This is the major data input device for the system. The A/D converter is presently equipped with a programmable pacer, 32 channels of high-level, and 16 channels of low-level programmable gain (seven gain steps giving a range between ± 5 MV and ± 1.25 V). All channels are differentially connected to suppress noise. Four empty card slots are available for expansion of up to 64 additional channels.

The HP-2313 can be used in either a random or sequential channel access mode. For application flexibility, we have employed the unit only in the random access mode. In this mode, and including software conversion times, the average reading speed is ~ 150 microseconds per channel requested. The high-level channels have a voltage range of ± 10.24 V, with a 12-bit 2's complement binary word output. Voltage resolution is ~ 5 MV per bit.

The programmable pacer controls the sampling rate at which readings are taken. This can be done under program control using the computer interrupt system. The range of sample rates can be varied from one sample every 2550 seconds to 45,000 samples/s. This sample rate is programmed as a product of a variable microsecond time base between 0 and 255 and an integer power of 10 between 0 and 7.

To make it easier to connect signals to the A/D unit, maintain flexibility, and allow untrained personnel to use the system, all A/D channels are precabled to a connector bank mounted outside the computer enclosure. Connecting a new signal source then involves only mating to the appropriate pins of the connector. It is not necessary to go into the HP 2313 and manipulate internal connectors.

With this approach, modifications can be made to the experiments without risking damage to the A/D converter unit. Table II lists the connector pin and functions for the connectors mounted on the back of the computer rack.

TABLE II
Connector Designations for Computer Rack-Mounted Devices

<u>AN-Connector No. 1</u>		
<u>Pins Used</u>	<u>Computer Device</u>	<u>Functional Application</u>
A, R	A/D Chn 13	17/M Hi-Level Torque
C, D	A/D Chn 14	17/M Lo-Level Torque
E, F	A/D Chn 15	17/M Upper Shaft RPM
G, H	A/D Chn 16	17/M Motor Shaft RPM
J, K	A/D Chn 17	17/M 100' Wind Velocity
L, M	A/D Chn 18	17/M 80' Wind Velocity
N, P	A/D Chn 19	17/M 100' Wind Direction
R, S	A/D Chn 20	5/M Torque Output
T, U	A/D Chn 21	5/M Fence Wind Velocity
V, W	A/D Chn 22	5/M Centerline Wind Velocity
X, Y	Relay Chn 10	Unassigned
Z, a	Relay Chn 11	
b, c	Relay Chn 12	
d, e	Relay Chn 13	
f, g	Relay Chn 14	
h, i	Relay Chn 15	
j, k	Relay Chn 16	
m, n	Relay Chn 17	
p, q	Relay Chn 18	
r, s	Relay Chn 19	
t, u	Relay Chn 20	

<u>AN-Connector No. 2</u>		
<u>Pins Used</u>	<u>Computer Device</u>	<u>Functional Application</u>
A, B	A/D Chn 23	Tower 12' Velocity
C, D	A/D Chn 24	Tower 34' Velocity
E, F	A/D Chn 25	Tower 58' Velocity
G, H	A/D Chn 26	Tower 100' Velocity
J, K	A/D Chn 27	Tower 12' Direction
L, M	A/D Chn 28	Tower 34' Direction
N, P	A/D Chn 29	Tower 58' Direction
R, S	A/D Chn 30	Tower 100' Direction
T, U	A/D Chn 31	2M Wind Vel.
V, W	A/D Chn 32	2M Wind Dir
X, Y	Relay Chn 21	
Z, a	Relay Chn 22	
b, c	Relay Chn 23	
d, e	Relay Chn 24	
f, g	Relay Chn 25	
h, i	Relay Chn 26	
j, k	Relay Chn 27	
m, n	Relay Chn 28	
p, q	Relay Chn 29	
r, s	Relay Chn 30	
t, u	Relay Chn 31	
v, w	Relay Chn 32	

Jones Strip Block

<u>Screw Pair Connectors</u>	<u>Computer Device</u>	<u>Functional Application</u>
1	A/D Chn 1	Induction Motor Power
2	A/D Chn 2	Induction Motor Current
3	A/D Chn 3	Induction Motor Voltage
4	A/D Chn 4	Sychnc. Gen. Power
5	A/D Chn 5	2M Torque
6	A/D Chn 6	Unassigned
7	A/D Chn 7	
8	A/D Chn 8	
9	A/D Chn 9	
10	A/D Chn 10	
11	A/D Chn 11	
12	A/D Chn 12	
13	Relay Chn 1	
14	Relay Chn 2	
15	Relay Chn 3	
16	Relay Chn 4	
17	Relay Chn 5	
18	Relay Chn 6	
19	Relay Chn 7	
20	Relay Chn 8	
21	Relay Chn 9	
22	A/D Chn 32 (Low Level)	North Guy Wire
23	A/D Chn 33 (Low Level)	South Guy Wire
24	A/D Chn 34 (Low Level)	East Guy Wire
25	A/D Chn 35 (Low Level)	West Guy Wire

Operator's Console and Graphics Plotter

The operator's console is a Tektronix 4014-1 CRT terminal with a mating Tektronix 4631 hardcopy unit. This terminal is a memory scope/keyboard combination that allows for alpha and graphic mode operations. We have provided no other listing device with this system.

In the alpha mode the terminal provides interactive keyboard capability with a 9600-baud output rate. When placed in the graphics mode, the terminal can be used as a high-speed, high-resolution plotter (1024 horizontal points, 780 vertical-axis points).

The 4631 hardcopy unit provides acceptable report-quality copies of the screen contents. Used with the automatic copy command features, the terminal/hardcopy pair can be a moderate-speed listing device or graphic output unit. Tektronix-furnished plotting software has been modified by Sandia Laboratories to provide a hardware/software plotting capability for this system.⁹ A key element in the successful use of this system has been the flexibility provided by the terminal/hardcopy pair.

Magnetic Disk System

The system disk is an HP-7905 moving head disk containing one fixed and one removable disk platter. The two surfaces of the removable-disk platter provide a maximum storage capability of 5 million 16-bit words. Only one surface of the fixed platter can be used for storage (the second surface is used for disk control features), providing 2.5 million words. Total active storage for the disk then is 7.5 million 16-bit words. With appropriate program techniques and interchanging removable platters, an "infinite" total storage can be achieved.

Generally, the fixed-disk platter is the depository for the system operating software, while the removable platter acts as the data storage area. But it should be understood that the operating software has equal access to all disk surfaces. Programs and data can be stored and accessed from appropriately named files located on any surface under program control.

Magnetic Tape System

The second mass storage system is an HP-7970E magnetic tape system. This tape system, a 1600-bpi, 45-ips, nine-track, phase-encoded unit, is compatible with tape drives generally found on large central computing facilities. The major reason for procuring the tape system was to provide a convenient way to transfer data between our minicomputer system and other large-scale systems. This option has not been used primarily because of the graphic and analytic capabilities of the minicomputer; there has been no incentive to go to the large-scale systems.

System Software

Operating System Software

The software operating system chosen for the system was HP's DOS III. DOS III supports the following:

1. FORTRAN IV compiler
2. File text editor
3. Named file system

4. Assembler
5. Interrupt and direct memory access (DMA) operations
6. Relocatable loader (capable of loading FORTRAN and assembly-level subroutines)

Although reasonably powerful, the DOS III allows only ~24,000 memory words for the operating user program area. Considering the power of the operating system, this is a very large program area.

The major disadvantages of the DOS III system are its lack of time-oriented tasking functions and the slowness of the compiler and assembler.

A nonstandard FORTRAN feature under DOS known as the "executive," allows FORTRAN programs access to all peripheral devices and the named files. The executive call is a FORTRAN statement resembling the usual subroutine call format. Arguments provided for in the call format specify the operation desired, logical unit involved (if any), file name, number of data words, and relative starting location of data transfer. When executed in an operating program, this executive call uses available monitor routines to perform the specified functions. A programmer familiar with standard FORTRAN subroutine operations can quickly use this feature to access the file system or DMA-type transfers.

Assembly Language Programs

As described above, the executive-call feature provides access to the standard data-handling peripherals (the PCM system interface is designed to have DMA to the system and is controlled then by a variation of the executive call). The A/D converter, relay units and digital-to-analog (D/A) units do not fit under the executive format.

To forestall the need for programmers to write difficult assembly-language routines for these units in each application program, five general-purpose assembly language subroutines are provided. These subroutines may be loaded with a main FORTRAN program and executed by using standard FORTRAN call statements. Arguments are provided to ensure much flexibility in the use of the subroutines. Where appropriate, the arguments are keyed to hardware features of the devices. Under this approach FORTRAN-oriented programmers have full command over all features of the system.

The following are argument descriptions for each call. Appendix A lists each assembly-language routine. Note that the program PADC includes two entry calls, GAIN and PADC.

1. Form of FORTRAN call

CALL GAIN (N)

This call varies the gain of the low-level A/D channels. The argument N can be an integer constant or variable name between 1 and 7. Resulting gains are

0 = 1000	4 = 100
1 = 500	5 = 50
2 = 250	6 = 25
3 = 125	7 = 12.5

The GAIN call sets A/D channels 33 to 48 to the specified gain. If GAIN is not called in the program, a default gain of 500 is in effect.

2. Form of FORTRAN call

CALL PADC (N, ICH, V, IPER, IBASE, IST, NAM)

N - May be a constant or integer variable; it defines the number of channels to be read.

ICH - Name of a previously defined array. Array locations from ICH(1) to ICH(N) must be assigned the appropriate channel numbers to be read. Channel number may be in any sequence.

V - The name of a previously defined floating point array. The floating point voltage results are returned in this array in the sequence in which they are read.

IPER, IBASE - May be integer constants or variables. These two arguments control the sampling rate at which the A/D unit will operate. IPER must have a value between 0 and 255; this number is a microsecond factor. IBASE must have a value between 0 and 7 and is considered a power-of-10 exponent. IPER equal 1 and IBASE equal 6 specifies a 1-s period, IPER equal 5, IBASE equal 6 specifies a sampling period of 0.5s. If IPER and IBASE equal 0, no interrupts will occur; only the first set of readings will be taken.

IST - Must be an integer variable name; it must not be an integer constant. IST is employed as a flag for the system. Generally IST is preset to zero (0) prior to making the IST PADC call. Each time the system takes a set of readings, the software will increase IST by N. This allows one to build a logic loop checking the value of IST to determine if a new set of readings has been taken. If IST is set to a negative value when called, the system will use the optional subroutine argument during each interrupt sequence.

NAM - Must be the name of a subroutine compiled with the main FORTRAN program; the subroutine must contain two arguments N, V. If IST is set negative on the first call, each interrupt sequence will jump to this subroutine setting the correct values for N and V. This feature allows a FORTRAN programmer to accumulate data at a specified interrupt sampling rate while his main program performs other duties. This feature is optional, and the argument NAM may be omitted; if omitted, care must be taken to ensure that IST is not negative when the PADC call is made.

CAUTION

In all cases where PADC is used, a call to PADC should be made with IPER and IBASE equal 0 before the program is terminated. Failure to do this will cause system monitor errors, as the A/D converter will continue to cause interrupts to a memory area that may be used by the monitor after program termination.

RELAY CONTROL CALL

CALL RELAY (N, ICH)

N - Number of relays affected by the call. Argument may be either an integer constant or variable.

ICH - A predimensioned integer array. Values of ICH(1) to ICH(N) must be assigned arguments representing relay channel numbers. A positive argument will cause the relay to close its normally open contact; a negative argument will open the contact. After a call to RELAY, all relays maintain their settings until the next call.

DIGITAL-TO-ANALOG CONVERTER CALL

CALL DAC (N, ICH, V)

This call is used to obtain program-controlled analog voltages. A voltage range of ± 10 V is obtainable with a 5-MV resolution.

N - May be either an integer variable or constant.

ICH - Must be a predimensioned integer array. The locations ICH(1) to ICH(N) must be assigned values corresponding to the DAC channels to be modified.

V - Must be a predimensioned real array. The locations V(1) to V(N) must be assigned values corresponding to the voltages desired on the corresponding DAC channels.

Appendix C lists the assembly-level programs used to implement these calls.

3. FORTRAN Examples

To illustrate the use of a call in a FORTRAN program, the following program demonstrates the use of PADC. The program reads A/D channels 5, 3 and 4, reading the three channels every 0.25 s. Ten readings are stored in an array group.

C - The dimension statement establishes necessary FORTRAN array spaces.

DIMENSION ICH(10), V(10), STOR1(10), STOR2(10), STOR3(10).

C - The following statements set number of channels to be read,

C - assigns channel numbers, sets the sampling period of 0.25

C - s and finally initializes the flag word IST.


```

N = 3
ICH(1) = 5
ICH(2) = 3
ICH(3) = 4
IPER = 25
IBASE = 4
IST = 0

```

C - The variable ICOUNT is used to count the number of readings
C - (interrupt sequences).

```
ICOUNT = 0
```

C - The following two lines calls PADC turning on the A/D
C - unit and set in as a comparison value to check for when
C - interrupts have occurred.

```
CALL PADC (N, ICH, V, IPER, IBASE, IST)
IN = IST
```

C - The following single line loop waits for interrupts to modify IST.

```
10 (IN . EQ . IST) GO TO 10
```

C - The following lines modify IN to match the new value of
C - IST, stores voltage readings into their permanent place
C - and checks the number of interrupts to determine if the pro-
C - gram should terminate.

```
IN = IST
NI = NI + 1
STOR1(NI) = V(1)
STOR2(NI) = V(2)
STOR3(NI) = V(3)
IF (NI . EQ . 10) GO TO 20
GO TO 10
```

C - The final line causes the A/D unit to halt its interrupt
C - processes by calling PADC again with ϕ arguments in the
C IPER, IBASE position.

```
20 CALL PADC (N, ICH, V,  $\phi$ ,  $\phi$ , IST)
STOP
```

Appendix B is a listing of a FORTRAN program to acquire data from specified PCM channels and automatically plot the data in limits of microstrain vs time in seconds. A review of this program will show that it is almost indistinguishable from a FORTRAN program used on large-scale machines to perform similar scaling and plotting operations.

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APPENDIX A
Assembly-Level Language Programs

:LI,5,1,.PADC

```

0001 ASMB,R,L,F
0002      NAM %PADC,7
0003 *
0004      ENT PADC,GAIN
0005      EXT .ENTR,EXEC,.GARD
0006 *
0007 *   GAIN SETS GAIN OF LOW LEVEL MPX
0008 *   CALL GAIN(IG) WHERE IG=0 G=1000
0009 *   1=500(DEFAULT),2=250,3=125,4=100
0010 *   5=50, 6=25,7=12.5 (THATS IT)
0011 *
0012 GAN OCT 1   DEFAULT GAIN OF 500
0013 IG BSS 1   ARG ADDESS PASSED
0014 GAIN NOP   ENTRY POINT
0015 JSB .GARD  GET ARG ADDRESS
0016      DEF IG
0017 LDA IG,I   GET GAIN NUMBER
0018 STA GAN    STORE FOR LATER USE
0019 JMP GAIN,I  RETURN
0020 *
0021 *
0022 *
0023 *   CALL PADC(N,ICH,U,IBASE,IPER,IST,SUBN)
0024 *   WILL CAUSE PACED READINGS TIMED PER IBASE&IPER
0025 *   SUBN IS OPTIONAL MUST HAVE A NEG. IST WHEN CALLED
0026 *   TO GO TO SUBN--- CALL WITH IBASE,IPER=0
0027 *   STOPS PACER
0028 *
0029 B EQU 1B
0030 U2313 EQU 11B   SELECT CODE DEFINITION
0031 *
0032 N BSS 1
0033 ICH BSS 1
0034 U BSS 1
0035 IBASE BSS 1
0036 IPER BSS 1
0037 IST BSS 1
0038 SUBN BSS 1
0039 *
0040 PADC NOP   ENTRY POINT
0041 JSB .ENTR  GET ARGUMENTS
0042 DEF N
0043 *
0044 LDA MPFLG
0045 STA MPSAV   SAVING MEM PROTECT STATUS
0046 SZA
0047 JMP MOFF
0048 JSB EXEC
0049 DEF *+3
0050 DEF RC30
0051 DEF D1
0052 MOFF CLF 0
0053 *
0054 *
0055 CLC U2313
0056 LDA =B140001  INITIALIZE SUB SYSTEM

```

```

0057      OTA U2313
0058      STC U2313,C      ENCODE
0059      NOP
0060      STC U2313      ENCODE WITH OUT C ?
0061      SFS U2313
0062      JMP *-1
0063      *
0064      *
0065      LDA -B100140      DUMMY READING CN 0 SLOT 3
0066      OTA U2313
0067      STC U2313,C
0068      SFS U2313
0069      JMP *-1
0070      *
0071      LDA -B040240      GAIN ENABLE WORD SLOT 5
0072      OTA U2313
0073      STC U2313,C
0074      SFS U2313
0075      JMP *-1
0076      LDA GAN      GET GAIN NUMBER
0077      OTA U2313      SEND OUT
0078      STC U2313,C
0079      SFS U2313
0080      JMP *-1
0081      *
0082      CLA
0083      STA FLAG1      IF - NEED SUBN STUFF
0084      LDA IST,I
0085      SSA,RSS      SKIP IF -
0086      JMP POSA      NO FOTRAN SUBN
0087      STA FLAG1      SAVE - FLAG
0088      POSA      JSB READ
0089      *
0090      LDA IPER,I      PICK UP MULT. FOR PACER
0091      ASL 8      SHIFT IT
0092      LDB IBASE,I      BASE TIME
0093      IOR 1B      OR IT WITH A
0094      IOR -B060000      OR REST OF CONTROL
0095      *
0096      *
0097      LDB TRP      SETTING UP TRAP VECTOR
0098      STB U2313
0099      LDB LINK      LINK CONTAINS INTR ADDRESS
0100      STB 310B      STORE ON BASE PAGE LOCATION
0101      *
0102      OTA U2313
0103      STC U2313,C      ENCODE PACE TIME CONTROL
0104      SFS U2313
0105      JMP *-1
0106      *
0107      *
0108      LDA -B130140      DUMMY READING FOR PACED TIME
0109      OTA U2313
0110      STC U2313,C
0111      *

```

```

0112      LDA MPSAU   CHECK OLD FLAG STS
0113      SZA
0114      JMP WSOFF
0115      STF 0
0116      JSB EXEC
0117      DEF *+3
0118      DEF RC30
0119      DEF D0
0120      JMP PADC,I
0121 WSOFF  STF 0
0122      JMP PADC,I  RETURN WAIT FOR INTERRUPTS
0123      *
0124      *
0125      *
0126 PINTR  NOP      ENTRY POINT FOR INTRRUPTS
0127      CLF 0      NO MORE ALLOWED
0128      STA SAUA   SAVE REGS A,B,E,Q,X,Y
0129      STB SAUB
0130      ERA,ALS
0131      SOC
0132      INA
0133      STA SAVE0
0134      STX SAUX
0135      STY SAVY
0136      *
0137      *
0138      LDA MPFLG   SAVING MPSTS
0139      STA MPSAU
0140      CLA,INA
0141      STA MPFLG
0142      JSB READ    GO READ
0143      *
0144      CLC U2313   DISABLE A/D
0145      LDA FLAG1   TEST FOR SUBR JUMP
0146      SSA,RSS
0147      JMP INT2    JUMP IF -
0148      LDB SUBN    ADDRESS OF FORT.SUB
0149      ADB -D-2    FORM ADD. OF N ARG
0150      LDA N
0151      STA B,I     STORE ADDRESS LIKE .ENTR WOULD DO
0152      INB PUSH POINTER
0153      LDA U
0154      STA B,I     STORE U ADDRESS
0155      INB ENTRY POINT
0156      INB POINT TO JSB .ENTR
0157      LDA B,I     GOING TO SAVE IT
0158      STA TEMP1
0159      CLA
0160      STA B,I     NOP OLD INST
0161      INB POINT TO DEF N+1 LOC.
0162      LDA B,I
0163      STA TEMP2
0164      CLA
0165      STA B,I
0166      JSB SUBN,I   GO DO IT
0167      LDB SUBN    GOING TO RESTORE
0168      INB
0169      LDA TEMP1
0170      STA B,I
0171      INB

```

```

0172      LDA TEMP2
0173      STA B,I
0174  INT2  NOP
0175      LDB MPSAU  CHK ON ORIG MP STS
0176      SZB
0177      JMP MPOFF
0178      STB MPFLG
0179      JSB RESTR
0180      LDA -B110140  PAGED DUMMY READING
0181      OTA U2313
0182      LDA SAUA
0183      STC U2313,C
0184      STF 0
0185      STC 5
0186      JMP PINTR,I
0187  MPOFF STB MPFLG  RESTORE STS WORD
0188      JSB RESTR  REGS RESTORED
0189      LDA -B110140
0190      OTA U2313
0191      LDA SAUA
0192      STC U2313,C
0193      STF 0
0194      JMP PINTR,I
0195      *
0196      *
0197      *
0198  RESTR  NOP
0199      LDA SAVE0
0200      CLO
0201      SLA,ELA
0202      STF 1
0203      LDA SAUA
0204      LDB SAUB
0205      LDX SAUX
0206      LDY SAUY
0207      JMP RESTR,I
0208      *
0209  SAVE0  NOP
0210  SAUA   NOP
0211  SAUB   NOP
0212  SAUX   NOP
0213  SAUY   NOP
0214      *
0215  READ   NOP  READ SUB
0216      LDA N,I  GET NUMOF READS
0217      CMA,INA  MAKE NEG
0218      STA TAG  STORE IN COUNT LOC.
0219      LDA ICH  ADDRESS OF CHNS
0220      STA TAG+1 STORE IN TEMP LOCATION
0221      LDA U  ADDRESS OF RESULTS
0222      ADA -D-2  SUBT 2 FOR LOOP
0223      STA TAG+2
0224      *
0225  LOOP  LDA TAG+1,I  GET CHN NUM

```



```

0226      ADA =D-33      TEST FOR LLMPX CHN 33-48
0227      SSA,RSS      SKIP CHN < 33 A IS -
0228      JMP LLMPX
0229      LDA TAG+1,I    RESTORE A
0230      ADA =D-17      TST FOR HLMPX CHNS 17-32
0231      SSA
0232      JMP LOOP1      CHN NUM 1-16
0233      ALS FORM (N-1)*2
0234      IOR =B100200    MPX SLOT 4
0235      JMP CONT
0236  LLMPX  ALS
0237      IOR =B100240    SLOT 5 LLMPX
0238      JMP CONT
0239      *
0240      *
0241  LOOP1  LDA TAG+1,I    GET CHN NUM
0242      ADA =D-1      CONVERT TO DIFF CHN NUM
0243      ALS          (N-1)*2
0244      *
0245      IOR =B100140    FORM MPX,RANDOM,BOX 0,SLOT 3 CHN NUM
0246  CONT   OTA U2313      MOV CONTROL WRD
0247      STC U2313,C
0248      SFS U2313
0249      JMP *-1
0250      LIA U2313      GET DATA
0251      ISZ TAG+1
0252      ISZ IST,I      INC IST TO SHOW LIFE
0253      NOP          IN CASE WE GET A 0 ABOVE
0254      ISZ TAG+2
0255      ISZ TAG+2      INC FLOATING POINT ADDR 2X'S
0256      ARS,ARS
0257      ARS,ARS      SHIFT OUT STS BITS FROM DATA
0258      FLT          FLT 12 BITS TO A,B REGS
0259      FMP FACTR      MULT BY CON FACTOR
0260      DST TAG+2,I    STORE RESULT
0261      ISZ TAG          ARE WE DONE
0262      JMP LOOP
0263      JMP READ,I      RETURN FROM SUB
0264      *
0265      *
0266  MP3AV   NOP
0267  TAG     BSS 3
0268  D0      DEC 0
0269  D1      DEC 1
0270  RC30    DEC 30
0271  FACTR   DEC .005
0272  TRP     JSB PLINK,I
0273  PLINK   EQU 310B
0274  LINK    DEF PINTR
0275  MPFLG   EQU 271B
0276  FLAG1   NOP
0277  CLRCN   CLC U2313
0278  TEMP1   NOP
0279  TEMP2   NOP
0280      *
0281      END
**** LIST END ****
e

```

APPENDIX B

FORTRAN Program STRAN

(Acquires data from the PCM and provides plotting capability)

```
:LI,S,1,.IADC
```

```

0001 ASMB,R,L,F
0002      NAM %IADC,7
0003 *    THIS SUB RETURNS INTEGER VALUES FROM THE A/D CONVERTER
0004 *
0005      ENT IADC,IGAIN
0006      EXT .ENTR,EXEC,.GARD
0007 *
0008 *    GAIN SETS GAIN OF LOW LEVEL MPX
0009 *    CALL GAIN(IG) WHERE IG=0 G=1000
0010 *    1=500(DEFAULT),2=250,3=125,4=100
0011 *    5=50, 6=25,7=12.5 (THATS IT)
0012 *
0013 GAN OCT 1    DEFAULT GAIN OF 500
0014 IG BSS 1    ARG ADDRESS PASSED
0015 IGAIN NOP ENTRY POINT
0016 JSB .ENTR GET ARG ADDRESS
0017 DEF IG
0018 LDA IG,I GET GAIN NUMBER
0019 STA GAN STORE FOR LATER USE
0020 JMP IGAIN,I RETURN
0021 *
0022 *
0023 *
0024 *    CALL IADC(N,ICH,IBUFF,IBASE,IPER,IST,SUBN)
0025 *    RETURNS INTEGER ARRAY IN IBUFF OTHERWISE LIKE PADC
0026 *    WILL CAUSE PACED READINGS TIMED PER IBASE&IPER
0027 *    SUBN IS OPTIONAL MUST HAVE A NEG. IST WHEN CALLED
0028 *    TO GO TO SUBN--- CALL WITH IBASE,IPER=0
0029 *    STOPS PACER
0030 *
0031 B EQU 1B
0032 U2313 EQU 11B SELECT CODE DEFINITION
0033 *
0034 N BSS 1
0035 ICH BSS 1
0036 U BSS 1
0037 IBASE BSS 1
0038 IPER BSS 1
0039 IST BSS 1
0040 SUBN BSS 1
0041 *
0042 IADC NOP ENTRY POINT
0043 JSB .ENTR GET ARGUMENTS
0044 DEF N
0045 *
0046 LDA MPFLG
0047 STA MPSAU SAVING MEM PROTECT STATUS
0048 SZA
0049 JMP MOFF
0050 JSB EXEC
0051 DEF *+3
0052 DEF RC30
0053 DEF D1
0054 MOFF CLF 0
0055 *
0056 *
0057 CLC U2313

```

```

0058      LDA =B140001  INITIALIZE SUB SYSTEM
0059      OTA U2313
0060      STC U2313,C    ENCODE
0061      NOP
0062      STC U2313      ENCODE WITH OUT C ?
0063      SFS U2313
0064      JMP *-1
0065      *
0066      *
0067      LDA =B100140  DUMMY READING ON 0 SLOT 3
0068      OTA U2313
0069      STC U2313,C
0070      SFS U2313
0071      JMP *-1
0072      *
0073      LDA =B040240  GAIN ENABLE WORD SLOT 5
0074      OTA U2313
0075      STC U2313,C
0076      SFS U2313
0077      JMP *-1
0078      LDA GAN  GET GAIN NUMBER
0079      OTA U2313  SEND OUT
0080      STC U2313,C
0081      SFS U2313
0082      JMP *-1
0083      *
0084      CLA
0085      STA FLAG1      IF - NEED SUBN STUFF
0086      LDA IST,I
0087      SSA,RSS        SKIP IF -
0088      JMP POSA      NO FOTRAN SUBN
0089      STA FLAG1      SAVE - FLAG
0090      POSA  JSB READ
0091      *
0092      LDA IPER,I    PICK UP MULT. FOR PACER
0093      ASL 8          SHIFT IT
0094      LDB IBASE,I    BASE TIME
0095      IOR 1B         OR IT WITH A
0096      IOR =B060000  OR REST OF CONTROL
0097      *
0098      *
0099      LDB TRP      SETTING UP TRAP VECTOR
0100      STB U2313
0101      LDB LINK     LINK CONTAINS INTR ADDRESS
0102      STB 310B     STORE ON BASE PAGE LOCATION
0103      *
0104      OTA U2313
0105      STC U2313,C   ENCODE PACE TIME CONTROL
0106      SFS U2313
0107      JMP *-1
0108      *
0109      *
0110      LDA =B130140  DUMMY READING FOR PACED TIME
0111      OTA U2313
0112      STC U2313,C
0113      *
0114      LDA MPSAU  CHECK OLD FLAG STS
0115      SZA
0116      JMP WSOFF
0117      STF 0
0118      JSB EXEC

```

```

0119      DEF *+3
0120      DEF RC30
0121      DEF D0
0122      JMP IADC,I
0123  WSOFF  STF 0
0124      JMP IADC,I
0125      *
0126      *
0127      *
0128  PINTR  NOP      ENTRY POINT FOR INTRRUPTS
0129      CLF 0      NO MORE ALLOWED
0130      STA SAUA      SAVE REGS A,B,E,O,X,Y
0131      STB SAUB
0132      ERA,ALS
0133      SOC
0134      INA
0135      STA SAVEDO
0136      STX SAUX
0137      STY SAUY
0138      *
0139      *
0140      LDA MPFLG      SAVING MPSTS
0141      STA MPSAU
0142      CLA,INA
0143      STA MPFLG
0144      JSB READ      GO READ
0145      *
0146      CLC      U2313 DISABLE A/D
0147      LDA FLAG1      TEST FOR SUBR JUMP
0148      SSA,RSS
0149      JMP INT2      JUMP IF -
0150      LDB SUBN      ADDRESS OF FORT.SUB
0151      ADB =D-2      FORM ADD. OF N ARG
0152      LDA N
0153      STA B,I      STORE ADDRESS LIKE .ENTR WOULD DO
0154      INB      PUSH POINTER
0155      LDA U
0156      STA B,I      STORE U ADDRESS
0157      INB      ENTRY POINT
0158      INB      POINT TO JSB .ENTR
0159      LDA B,I      GOING TO SAVE IT
0160      STA TEMP1
0161      CLA
0162      STA B,I      NOP OLD INST
0163      INB      POINT TO DEF N+1 LOC.
0164      LDA B,I
0165      STA TEMP2
0166      CLA
0167      STA B,I
0168      JSB SUBN,I      GO DO IT
0169      LDB SUBN      GOING TO RESTORE
0170      INB
0171      LDA TEMP1
0172      STA B,I
0173      INB
0174      LDA TEMP2
0175      STA B,I
0176  INT2    NOP
0177      LDB MPSAU      CHK ON ORIG MP STS
0178      SZB

```

```

0179          JMP MPOFF
0180          STB MPFLG
0181          JSB RESTR
0182          LDA =B110140  PAGED DUMMY READING
0183          OTA U2313
0184          LDA SAUA
0185          STC U2313,C
0186          STF 0
0187          STC 5
0188          JMP PINTR,I
0189 MPOFF     STB MPFLG  RESTORE STS WORD
0190          JSB RESTR  REGS RESTORED
0191          LDA =B110140
0192          OTA U2313
0193          LDA SAUA
0194          STC U2313,C
0195          STF 0
0196          JMP PINTR,I
0197 *
0198 *
0199 *
0200 RESTR     NOP
0201          LDA SAVEQ
0202          CLO
0203          SLA,ELA
0204          STF 1
0205          LDA SAUA
0206          LDB SAUB
0207          LDX SAUX
0208          LDY SAUY
0209          JMP RESTR,I
0210 *
0211 SAVEQ     NOP
0212 SAUA      NOP
0213 SAUB      NOP
0214 SAUX      NOP
0215 SAUY      NOP
0216 *
0217 READ     NOP      READ SUB
0218          LDA N,I  GET NUMOF READS
0219          CMA,INA  MAKE NEG
0220          STA TAG  STORE IN COUNT LOC.
0221          LDA ICH  ADDRESS OF CHNS
0222          STA TAG+1 STORE IN TEMP LOCATION
0223          LDA U    ADDRESS OF RESULTS
0224          ADA =D-1  SUBT 1 FOR LOOP
0225          STA TAG+2
0226 *
0227 LOOP     LDA TAG+1,I  GET CHN NUM
0228          ADA =D-33  TEST FOR LLMPX CHN 33-48
0229          SSA,RSS  SKIP CHN < 33 A IS -
0230          JMP LLMPX
0231          LDA TAG+1,I  RESTORE A
0232          ADA =D-17  TST FOR HLMPX CHNS 17-32
0233          SSA
0234          JMP LOOP1  CHN NUN 1-16
0235          ALS FORM (N-1)*2
0236          IOR =B100200  MPX SLOT 4
0237          JMP CONT
0238 LLMPX     ALS

```

```

0239      IOR =B100240  SLOT 5 LLMPX
0240      JMP CONT
0241      *
0242      *
0243  LOOP1  LDA TAG+1,I  GET CHN NUM
0244      ADA =D-1      CONVERT TO DIFF CHN NUM
0245      ALS          (N-1)*2
0246      *
0247      IOR =B100140  FORM MPX,RANDOM,BOX 0,SLOT 3 CHN NUM
0248  CONT  OTA U2313    MOV CONTROL WRD
0249      STC U2313,C
0250      SFS U2313
0251      JMP *-1
0252      LIA U2313  GET DATA
0253      ISZ TAG+1
0254      ISZ IST,I  INC IST TO SHOW LIFE
0255      NOP          IN CASE WE GET A 0 ABOVE
0256      ISZ TAG+2  INC ADDRESS TO STORE RESULT
0257      ARS,ARS
0258      ARS,ARS  SHIFT OUT STS BITS FROM DATA
0259      STA TAG+2,I  STORE REULT INTEGER
0260      ISZ TAG      ARE WE DONE
0261      JMP LOOP
0262      JMP READ,I  RETURN FROM SUB
0263      *
0264      *
0265  MPSAU  NOP
0266  TAG    BSS 3
0267  D0     DEC 0
0268  D1     DEC 1
0269  RC30   DEC 30
0270  FACTR  DEC .005
0271  TRP    JSB PLINK,I
0272  PLINK  EQU 310B
0273  LINK   DEF PINTR
0274  MPFLG  EQU 271B
0275  FLAG1  NOP
0276  CLRCN  CLC U2313
0277  TEMP1  NOP
0278  TEMP2  NOP
0279      *
0280      END
**** LIST END ****
@

```


:LI,S,1,.RELA

```

0001 ASMB,R,L,F
0002     NAM XRELA,7
0003     ENT RELAY
0004     EXT .GARD,EXEC
0005 *
0006 REL1 EQU 22B
0007 REL2 EQU 23B
0008 MPFLG EQU 271B
0009 *
0010 NR BSS 1
0011 IRE BSS 1
0012 RELAY NOP ENTRY -CALL RELAY(NR,IRE)
0013 *     IRE IS INT. ARRAY
0014 *
0015     JSB .GARD GET ARGUMENTS
0016     DEF NR
0017 *
0018     LDA MPFLG SAVE MP STS
0019     STA MPSAU
0020     SZA SKIP IF ON
0021     JMP MPOFF
0022     JSB EXEC TURN MP OFF
0023     DEF *+3
0024     DEF RC30
0025     DEF D1
0026 *
0027 MPOFF LDA NR,I GET NUM OF CHNS TO BE MODIFIED
0028     CMA,INA NEGATE IT
0029     STA NARGS
0030 *
0031 START LDA IRE,I GET FIRST CHN ADDRESS
0032     ISZ IRE BUMP POINTER
0033     SZA,RSS SKIP IF CHN ADD NOT 0
0034     JMP FINIS DONE NO CHN 0
0035 *
0036     SSA IF + CHN ADDRESS SKIP
0037     JMP MINUS GO OPEN RELAY
0038     JSB CHOSC GET CONTROL WORD
0039     ADA *D-1 DEC A CORRECT FOR 0 BIAS
0040     SZA,RSS SKIP IF NOT 0 WILL NOT SHIFT BIT
0041     JMP AROSF JMP AROUND SHIFT
0042     IOR SHFTI OR IN SHIFT INST
0043     STA SHFT STORE IT IN LINE
0044     CLA,INA
0045 SHFT NOP SHIFT INST WILL BE HERE
0046 ARO IOR CONWD OR IN CONTROL 1 OR 2
0047     STA CONWD PRESERVE MODIFIED WORD
0048 *
0049     ISZ NARGS DONE?
0050     JMP START NO
0051     JMP FINIS YES
0052 *
0053 AROSF CLA,INA TAKES CARE OF NO SHIFT CASE
0054     JMP ARO
0055 *
0056 *
0057 MINUS CMA,INA GET ITS POSITIVE VALUE

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```

0058          JSB CHOSC GO PICK CONWRD
0059          ADA =D-1  DEC A FOR 0 COMPATABILITY
0060          SZA,RSS
0061          JMP AROS1      JMP IF A=0
0062          IOR SHFT1 OR IN SHFT INST
0063          STA SHFT1
0064          CLA,INA  PLACE 1 IN BIT 0
0065 SHFT1      NOP
0066 ARO1      CMA  COMPLIMENT BIT WORD
0067          AND CONWD
0068          STA CONWD  SAVE IT
0069          JMP START
0070          *
0071 AROS1     CLA,INA
0072          JMP ARO1
0073          *
0074 FINIS     LDB CONWD
0075          OTB REL1  IST WRD OUT
0076          LDB CONWD
0077          OTB REL2
0078          *
0079          LDA MPSAV
0080          SZA
0081          JMP WSOFF
0082          JSB EXEC
0083          DEF *+3
0084          DEF RC30
0085          DEF D0
0086 WSOFF     JMP RELAY,I
0087          *
0088          *
0089          *
0090          * SUB TO PICK CORRECT CONTROL WORDS TO
0091          * BE MODIFIED WORDS ARE THEN PUT
0092          * IN PROGRAM LINE
0093          *
0094 CHOSC     NOP
0095          CAY  SAVE A IN REG Y
0096          ADA =D-16  16 CHN LIMIT ON CARD
0097          SZA,RSS  IF 0='S 16
0098          JMP E16
0099          SSA,RSS  SKIP ON NEG
0100          JMP GT16
0101 E16      CYA  GET A BACK  COME HERE FOR -16 OR
0102          LDB BANK1  LT 16
0103          STB ARO
0104          LDB BANK1+1
0105          STB ARO+1
0106          STB ARO1+2
0107          LDB BANK1+2
0108          STB ARO1+1
0109          JMP CHOSC,I
0110          *
0111 GT16     LDB BANK2

```

```

0112          STB ARO
0113          LDB BANK2+1
0114          STB ARO+1
0115          STB ARO1+2
0116          LDB BANK2+2
0117          STB ARO1+1
0118          JMP CHOSC,I
0119          *
0120          D16      DEC 16
0121          RC30     DEC 30
0122          D1       DEC 1
0123          D0       DEC 0
0124          SHFTI    OCT 100020
0125          CONWD    NOP
0126          CONW2    NOP
0127          *
0128          BANK1    IOR CONWD
0129          STA CONWD
0130          AND CONWD
0131          BANK2    IOR CONW2
0132          STA CONW2
0133          AND CONW2
0134          NARGS    NOP
0135          MPSAU    NOP
0136          *
0137          END
**** LIST END ****
@

```

:LI,5,1,.DAC

```

0001 ASMB,R,L,F
0002     NAM XDAC,7
0003     ENT DAC
0004     EXT .ENTR,EXEC
0005 *
0006 UMP EQU 10B
0007 MPFLG EQU 271B
0008 *
0009 NN     BSS 1  NUM OF CHNS TO BE MODIFIED
0010 ICN    BSS 1  INT. ARRAY FOR CHN NUMS
0011 UMO    BSS 1  REAL ARRAY FOR OUTPUT U'S
0012 *
0013 DAC    NOP     ENTRY--CALL DAC(NN,ICN,UMO)
0014     JSD .ENTR
0015     DEF NN
0016 *
0017     LDA MPFLG    CHK MP STS
0018     STA MPSAV    SAVE PRESENT STS
0019     SZA          SKIP IF MP ON
0020     JMP MPOFF
0021     JSB EXEC
0022     DEF *+3      CALL EXEC MP TURN OFF
0023     DEF RC30
0024     DEF D1
0025 *
0026 MPOFF  LDA NN,I  GET NUM OF CHNS
0027     CMA,INA     NEGATE IT
0028     STA NLOOP   SAVE FOR LOOP INCREMENTING
0029 *
0030 LOOP  LDA ICN,I  GET FIRST CHN TO BE MODIFIED
0031     ISZ ICN      INC POINTER
0032     ADA *D-1     SUB 1 FOR 0 CHN BIAS
0033     STA TEMP     SAVE IT
0034     LDB CON1     GET CONTROL WRD
0035 *           CONTROL WORD CONDITIONS DACS
0036     OTB UMP      OUT PUT IT
0037     NOP          STALL 8 USEC PER BOOK
0038     NOP
0039     NOP
0040     NOP
0041     NOP
0042     STC UMP,C    ENCODE CONTROL
0043     SFS UMP      SPIN UNTILL IT ACCEPTS CONTROL
0044     JMP *-1
0045 *
0046     DLD UMO,I    GET 1ST VOLTAGE
0047     ISZ UMO      INC POINTER
0048     ISZ UMO      2ND TIME REAL ARRAY
0049     FMP FCTR     MULT BY 12 BIT FACTOR
0050     FIX          FIX TO INTEGER IN REG A
0051     AND -B007777 CLR UPPER 4 SLOT BITS
0052 *           THESE HOLD CHN ID
0053     LDB TEMP     GET CHN NUM
0054     BLF          SHIFT 12 BITS
0055     BLF
0056     BLF
0057     IOR 1B      OR TO REG A

```

```

0058 *
0059     OTA UMP
0060     NOP
0061     NOP
0062     NOP
0063     NOP
0064     NOP
0065     STC UMP,C
0066 *           NO WAIT FOR FLAG
0067     ISZ NLOOP DONE?
0068     JMP LOOP NO
0069 *
0070     LDA MPSAU RESTORE MP AS NEEDED
0071     SZA
0072     JMP WSOFF
0073     JSB EXEC
0074     DEF *+3
0075     DEF RC30
0076     DEF D0
0077 *
0078     WSOFF JMP DAC,I
0079 *
0080     NLOOP NOP
0081     CON1 OCT 170160
0082     FCTR DEC 200.45
0083     RC30 DEC 30
0084     D1 DEC 1
0085     D0 DEC 0
0086     TEMP NOP
0087     MPSAU NOP
0088     END
**** LIST END ****
@

```

:LI,5,1,STRAN

```
0001  FTN4,L
0002  PROGRAM SPLI(3)
0003  COMMON TCS(134)
0004  DIMENSION IDATA(8000),IBUFF(256),ICHAN(5,5),ITU(6),ITH(5),
0005  1  STRAN(1000),TIME(1000),GSCAL(64),NAME1(3),IZERO(64)
0006  1  ,IVEL(3)
0007  EQUIVALENCE(GSCAL(1),IBUFF(129)),(IZERO(1),IBUFF(65))
0008  DATA ITU/2HMI,2HCR,2HQS,2HTR,2HAI,2HN /
0009  DATA ITH/2HTI,2HME,2H(M,2HSE,2HC)/
0010  DATA IVEL/2HV(,2HMP,2HH)/
0011  DATA NAME1/2HGA,2HGE,2H /
0012  ID = 2H*
0013  CALL EXEC(23,ID)
0014  CALL EXEC(18,NAME1,ISECT,0)
0015  IF(ISECT.NE.0)GO TO 5
0016  WRITE(1,17)
0017  17 FORMAT("GAGE FILE NOT FOUND")
0018  STOP
0019  5 CALL EXEC(14,2B,IBUFF,256,NAME1,0)
0020  WRITE(1,101)
0021  101 FORMAT("PCM CHANNEL",5X,"GAGE NUMBER",5X,
0022  1  "ZERO OFFSET",5X,"SCALE FACTOR")
0023  DO 103 I = 1,64
0024  IF(GSCAL(I).EQ.0.)GO TO 103
0025  102 FORMAT(5X,I2,12X,I4,14X,I4,10X,E10.4)
0026  WRITE(1,102) I, IBUFF(I),IZERO(I),GSCAL(I)
0027  103 CONTINUE
0028  WRITE(1,115)
0029  115 FORMAT("TO CHANGE CHANNEL NUMBERS, RUN PROG STRES")
0030  C
0031  2 DO 1 I = 1,5
0032  DO 1 J = 1,5
0033  1 ICHAN(I,J) = 0
0034  WRITE(1,10)
0035  10 FORMAT("ENTER NUMBER OF LINES TO PLOT(MAX OF 4)")
0036  READ(1,*) NLINE
0037  N = 1
0038  15 WRITE(1,11) N
0039  11 FORMAT("ENTER CHANNEL NUMBERS FOR LINE ",I2)
0040  I = 1
0041  READ(1,*) NO
0042  ICHAN(N,I) = NO
0043  13 IF(N.GE.NLINE)GO TO 27
0044  N = N + 1
0045  GO TO 15
0046  27 CONTINUE
0047  N = NLINE + 1
0048  ICHAN(N,1) = 33
0049  29 WRITE(1,28)
0050  28 FORMAT("ENTER NUMBER OF PCM SCANS FOR PLOTTER")
0051  READ(1,*)INSCNS
0052  ICHMN = 64
0053  ICHMX = 1
0054  DO 31 I = 1,5
0055  DO 31 J = 1,5
0056  IF(ICHAN(I,J).EQ.0)GO TO 31
0057  IF(ICHAN(I,J).LT.ICHMN)ICHMN = ICHAN(I,J)
```

```

0058      IF(ICHAN(I,J).GT.ICHMX)ICHMX = ICHAN(I,J)
0059      31 CONTINUE
0060      NCH = ICHMX-ICHMN+1
0061      LDATA = NCH*NSCNS
0062      IFBCD = ICHMN
0063      ILBCD = ICHMX
0064      CALL BNBOD(IFBCD)
0065      CALL BNBOD(ILBCD)
0066      IF (LDATA .GT. 8000)GOTO 29
0067      IDATA(1) = IFBCD
0068      IDATA(2) = ILBCD
0069      CALL EXEC(1,107B,IDATA,LDATA)
0070      CALL PCSC(LDATA,IDATA)
0071      NL = 1
0072      33 K = 1
0073      IT = 0
0074      DO 32 I = 1,LDATA
0075      IU = (I-1)/NCH
0076      ICH = I - IU*NCH + ICHMN - 1
0077      IF(ICH.NE.ICHAN(NL,K))GO TO 32
0078      IT = IT + 1
0079      IF(IT .GE. 1000) STOP 30
0080      TIME(IT) = .3*FLOAT(ICH) + FLOAT(IU)*20.
0081      SDATA = (IDATA(I) - IZERO(ICH))
0082      STRAN(IT) = SDATA*GSCAL(ICH)
0083      K = K + 1
0084      IF(ICHAN(NL,K) .EQ. 0) K = 1
0085      32 CONTINUE
0086      IF(NL .GT.NLINE) GO TO 47
0087      IF(NL .GT. 1) GO TO 46
0088      CALL PLOTS
0089      I1 = IT + 1
0090      I2 = IT + 2
0091      STRAN(I1) = -1000.
0092      STRAN(I2) = 500.
0093      IF(I2 .GE. 1000) STOP 31
0094      CALL SCALE(TIME,6.,IT,1)
0095      CALL AXIS(.5,.5,ITH,-10,6.,0.,TIME(I1),TIME(I2))
0096      CALL AXIS(.5,.5,ITU,12,5.,90.,STRAN(I1),STRAN(I2))
0097      CALL TGRID(.5,6.5,.5,5.5)
0098      CALL PLOT(.5,.5,-3)
0099      46 CALL LINE(TIME,STRAN,IT,1,0,NL)
0100      NL = NL + 1
0101      GO TO 33
0102      47 CALL PLOT(0.,3.0,-3)
0103      CALL AXIS(6.,0.,IUEL,-6,2.,90.,0.,30.)
0104      STRAN(I1) = 0.
0105      STRAN(I2) = 30.
0106      CALL LINE(TIME,STRAN,IT,1,5,NL)
0107      48 CALL ANMDE
0108      CALL TINPT(M)
0109      CALL PLOT(0.,0.,999)
0110      WRITE(1,50)
0111      50 FORMAT("MORE PLOTS?")
0112      READ(1,117) IANS
0113      117 FORMAT(A2)
0114      IF(IANS .EQ.2HYES) GO TO 2
0115      STOP
0116      END
0117      ENDS
**** LIST END ****
@

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