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A Data Acquisition and Instrument Control System for Laboratory Tests of an Ion Beam Source

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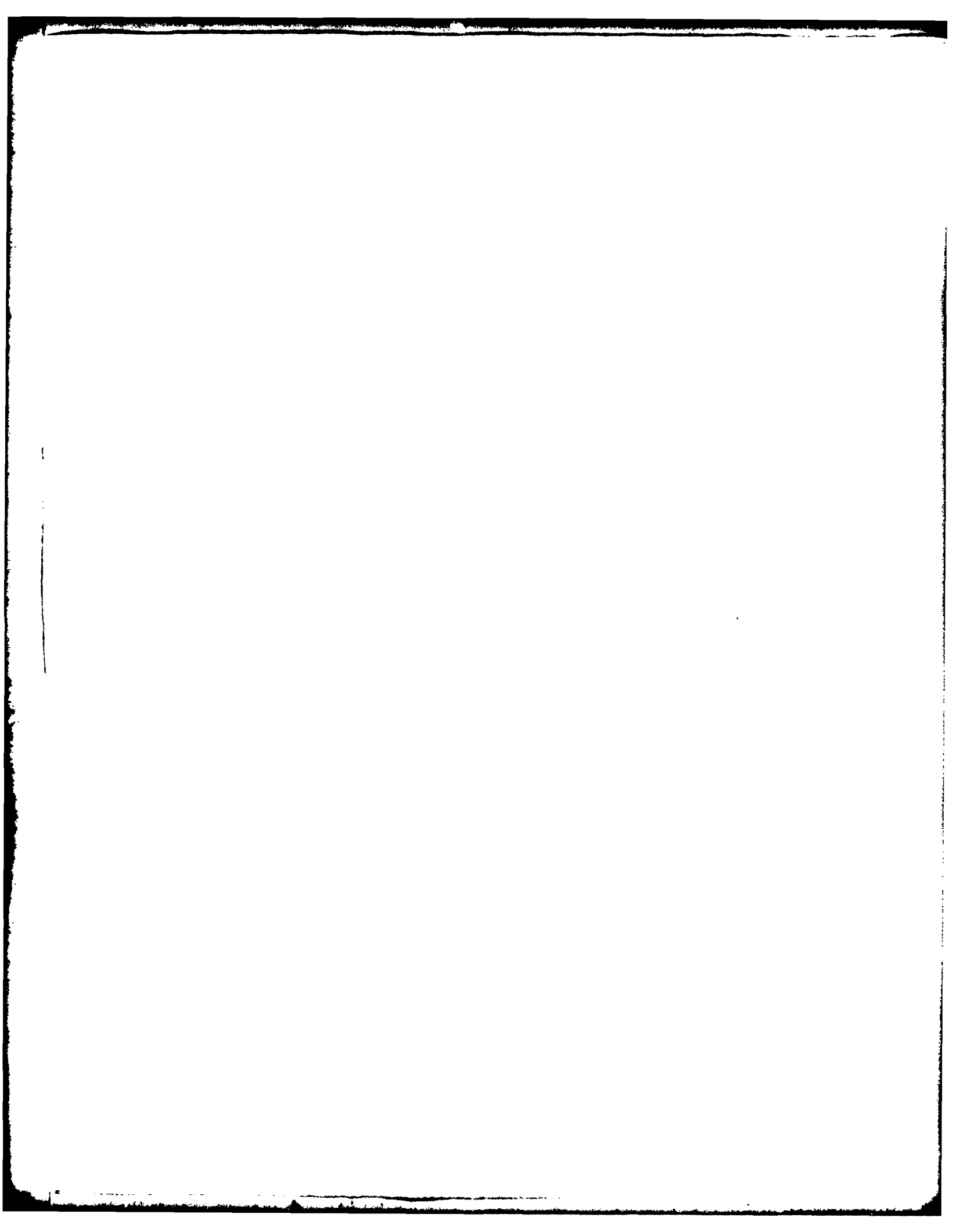
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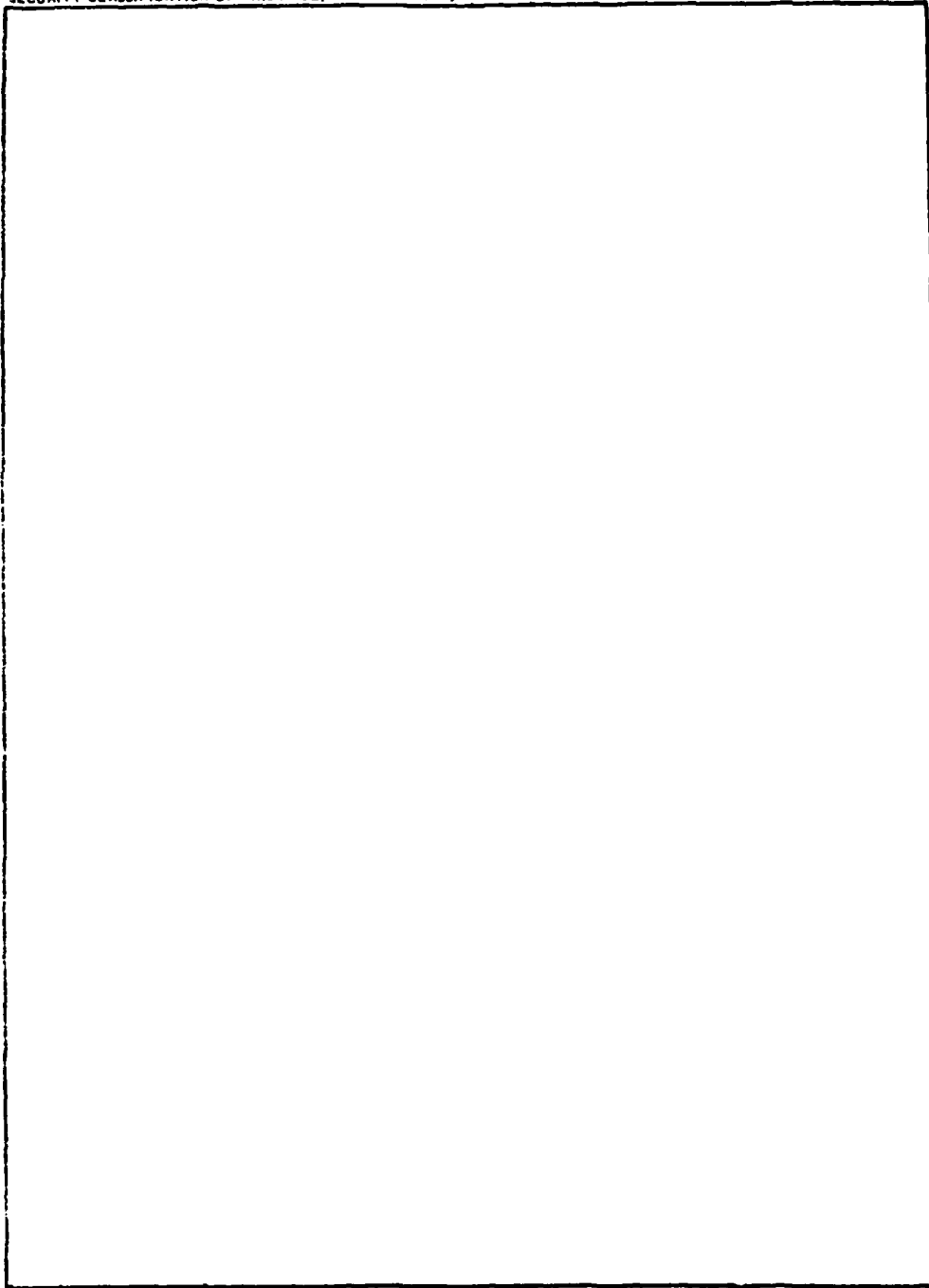
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A Data Acquisition and Instrument Control System for Laboratory Tests of an Ion Beam Source

1. INTRODUCTION

During the 1970's, the Air Force developed an ion beam source for use in spacecraft discharging experiments.^{1,2} In addition to the flight instruments, several models were developed for laboratory tests conducted at the Air Force Geophysics Laboratory. Over the past several years, the research methods used for the Satellite Positive Ion Beam System (SPIBS) tests have evolved from manual techniques for experiment control and data recording to the present use of a real-time, computer-based system. This system can perform data acquisition functions and, in addition, has experiment monitoring and instrument control capabilities.

2. SPIBS BACKGROUND

The Satellite Positive Ion Beam System (SPIBS; Figure 1) is a particle ejector capable of emitting a beam of positively charged ions. The ejector uses a Penning-type discharge to produce ions. This design requires from 25 to 60 W to produce a

(Received for publication 16 September 1981)

1. Masek, T. D., and Cohen, H. A. (1978) Satellite positive ion beam system, J. Spacecraft and Rockets, 15:27-33.
2. Stevens, J. R., and Vampola, A. L. (1978) Description of the Space Test Program P78-2 Spacecraft and Payload, SAMS0-TR-78-24, The Aerospace Corporation, El Segundo, California.

beam current range of 0.3 to 2.0 mA at energies of 1 and 2 keV. In addition, the ion beam system has a heated wire neutralizer that allows electron emission alone, or in combination with a positive ion beam to form a neutral plasma.

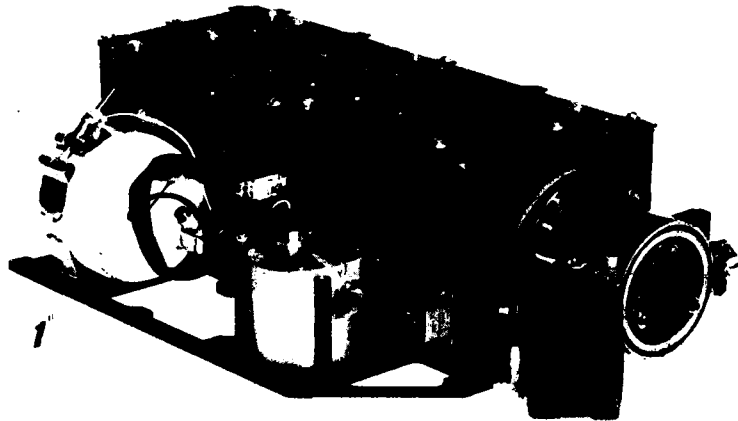


Figure 1. Satellite Positive Ion Beam System (SPIBS): Charged Particle Ejector Mounted on a Power Processor Assembly

Laboratory tests on the SPIBS are conducted using a vacuum chamber to simulate a space environment. The prototype model (Figure 2), the first functional version developed for preliminary experiments (1975-76), was tested in the vacuum chamber and controlled by power supplies outside the chamber. Instrument response was measured by analog meters and data were recorded by hand, requiring one person to initiate commands and read responses, and another person to record results. (Table 1 shows the instrument commands.) This involved considerable time to control, monitor, and record data for 18 channels of output (Table 2).

In developing the flight model, the power supplies were reduced in size and integrated into a power processor so that the particle ejector could be mounted directly on the processor. The entire unit could now be placed inside the vacuum chamber. This required the development of a control unit which would have the

capability of sending digital commands and receiving analog values (as a rough approximation of the commanding circuitry on a space vehicle payload). The control unit registered output on a one-channel digital voltmeter, thus still requiring manual sequential switching for readings of data.



Figure 2. SPIBS Prototype: Charged Particle Ejector

The data recording system developed for these early stages of experimentation was limited by the time required to complete the command-response-record cycle. The system did not have the capability of recording transient phenomena and did not allow comparisons of channels at the same time. As a result, recorded phenomena could only be viewed as isolated occurrences and were an incomplete description of events.

Table 1. SPIBS Instrument Commands*

Command	Function
1. Instrument on ^a	Turns on instrument power
2. Instrument off ^a	Turns off all instrument power
3. Expellant valve open	Opens solenoid valve
4. Expellant valve closed	Closes solenoid valve
5. Cathode heater preheat	Turns on the cathode heater to Level 1 and turns on discharge supply
6. Ion gun power on	Turns on the ion gun power
7. Ion gun power off	Turns off the ion gun power
8. Beam voltage Level 1	Sets the beam power supply to 1000 V
9. Beam voltage Level 2	Sets the beam power supply to 2000 V
10. Keeper off	Turns the keeper supply off
11. Discharge current and neutralizer emission Level 1	Sets the discharge current reference to achieve 20 mA current; sets neutralizer emission level to 0.4 mA
12. Discharge current and neutralizer emission Level 2	Sets the discharge current reference to achieve 125 mA current; sets neutralizer emission level to 1.2 mA
13. Discharge current and neutralizer emission Level 3	Sets the discharge current reference to achieve 200 mA current; sets neutralizer emission level to 2.2 mA
14. Neutralizer emission Level 4	Sets neutralizer emission level to 2 μ A
15. Neutralizer emission Level 5	Sets neutralizer emission level to 20 μ A
16. Neutralizer No. 1	Selects neutralizer filament No. 1
17. Neutralizer No. 2	Selects neutralizer filament No. 2
18. Neutralizer heater on	Turns on the neutralizer cathode heater on
19. Neutralizer heater off	Turns off the neutralizer bias
20. Neutralizer bias off	Turns off the neutralizer bias power supply
21. Neutralizer bias positive	Sets the neutralizer bias for positive polarity
22. Neutralizer bias negative	Sets the neutralizer bias for negative polarity
23. Neutralizer bias Level 1	Turns on the neutralizer bias to 10 V
24. Neutralizer bias Level 2	Turns on the neutralizer bias to 25 V
25. Neutralizer bias Level 3	Turns on the neutralizer bias to 100 V
26. Neutralizer bias Level 4	Turns on the neutralizer bias to 500 V
27. Neutralizer bias Level 5	Turns on the neutralizer bias to 1000 V
28. High voltage off	Turns off the beam and accel power supplies
29. Cathode conditioning	Turns on the cathode heater to Level 2

* From Masek, T. (1978) Satellite Positive Ion Beam System, Air Force Geophysics Laboratory, AFGL-TR-78-0141, pp 106-107.

^a In the SPIBS instrument, instrument on/off is implemented by connecting or disconnecting 28 V input power.

Table 2. SPIBS Analog Output Channels *

Channel No.	Description	Actual Value for 5 V Output, \pm 5%
1	Beam current	2.5 mA (\pm 2%)
2	Beam voltage	2500 V
3	Discharge current	250 mA
4	Discharge voltage	50 V
5	Keeper current	250 mA
6	Keeper high voltage	1000 V
7	Keeper low voltage	50 V
8	Cathode heater current	5 A
9	Accel current ^a	2.5 mA
10	Decel current ^a	2.5 mA
11	Neutralizer heater current	5 A
12	Neutralizer bias voltage	1000 V
13	Neutralizer emission ^b	2.5 mA (\pm 10%)
14	SPIBS net current ^b	2.5 mA (\pm 10%)
15	Tank pressure	1500 psia
16	Power processor temperature	See calibration curve
17	PPA ac inverter current	1.5 A
18	PPA ac inverter voltage	50 V

* From Masek, T. (1978) Satellite Positive Ion Beam System, Air Force Geophysica Laboratory, AFGL-TR-78-0141, p 100.

^aTo indicate anomolous condition.

^bIn three ranges: 2.5 to 25 μ A; 25 μ A to 250 μ A to 2.5 mA.

3. AUTOMATIC DATA RECORDING

A digital data printer was added in an attempt to incorporate automatic data recording. This increased the capability of the system because it released researchers from the responsibility of manually recording data, giving them more control over the experiment. Although the printer was capable of recording 20 values per sec, the data transfer from the voltmeter to the printer was limited by the analog-to-digital signal conversion in the voltmeter (five conversions, or channels, per sec). Another drawback was that unavoidable arcing within the

vacuum chamber (due to ion beam emissions) was liable to disrupt the printer synchronization; under these circumstances the data were unreliable. Also, the data required much time for analysis: digital data has to be converted to engineering units and then graphed.

Since data recording was limited by the time required for the analog-to-digital conversion, analog strip-chart recorders were used to record output from the SPIBS (1977-79). This represented a major improvement in data acquisition for SPIBS experiments, in that all 18 channels could be individually, simultaneously, and permanently recorded. (Three six-channel recorders were used.) The recorders allow a measurement of 0.05 V precision relative to a range of 0 to 5 V telemetry output from the SPIBS (one part in one hundred). The frequency response of the recorders is in the range of 60 to 100 Hz.

Although the use of strip-chart recorders increased the amount of recorded data, they required frequent calibration to maintain accuracy. The recorders allowed a certain amount of control over the time scaling by varying the chart speed, but it was difficult to identify the changes during data analysis. Although the data now included simultaneous recordings of the analog channels, comparisons between channels were a problem, particularly between channels on different recorders. Figure 3 shows an example of strip-chart recorder output.

4. COMPUTER-BASED DATA ACQUISITION AND CONTROL

The use of strip-chart recorders expanded the scope of the SPIBS experimentation by providing a continuous record of instrument output and a reasonable frequency response. However, the manpower required for operation and the time required for data reduction limited their usefulness. In 1980, a computer-based Data Acquisition and Instrument Control System (DAICS) was installed to take advantage of more efficient methods of data processing and to increase experiment control (Figure 4). It was designed to simulate satellite ground control systems, and thus had data acquisition, monitoring, and instrument control capabilities. The system is configured around a Digital Equipment Corporation PDP11/34A processor with a video terminal and a hardcopy terminal for input/output functions; magnetic disk and tape storage; and a graphics pen plotter. (Appendix A contains a list of the DAICS hardware.)

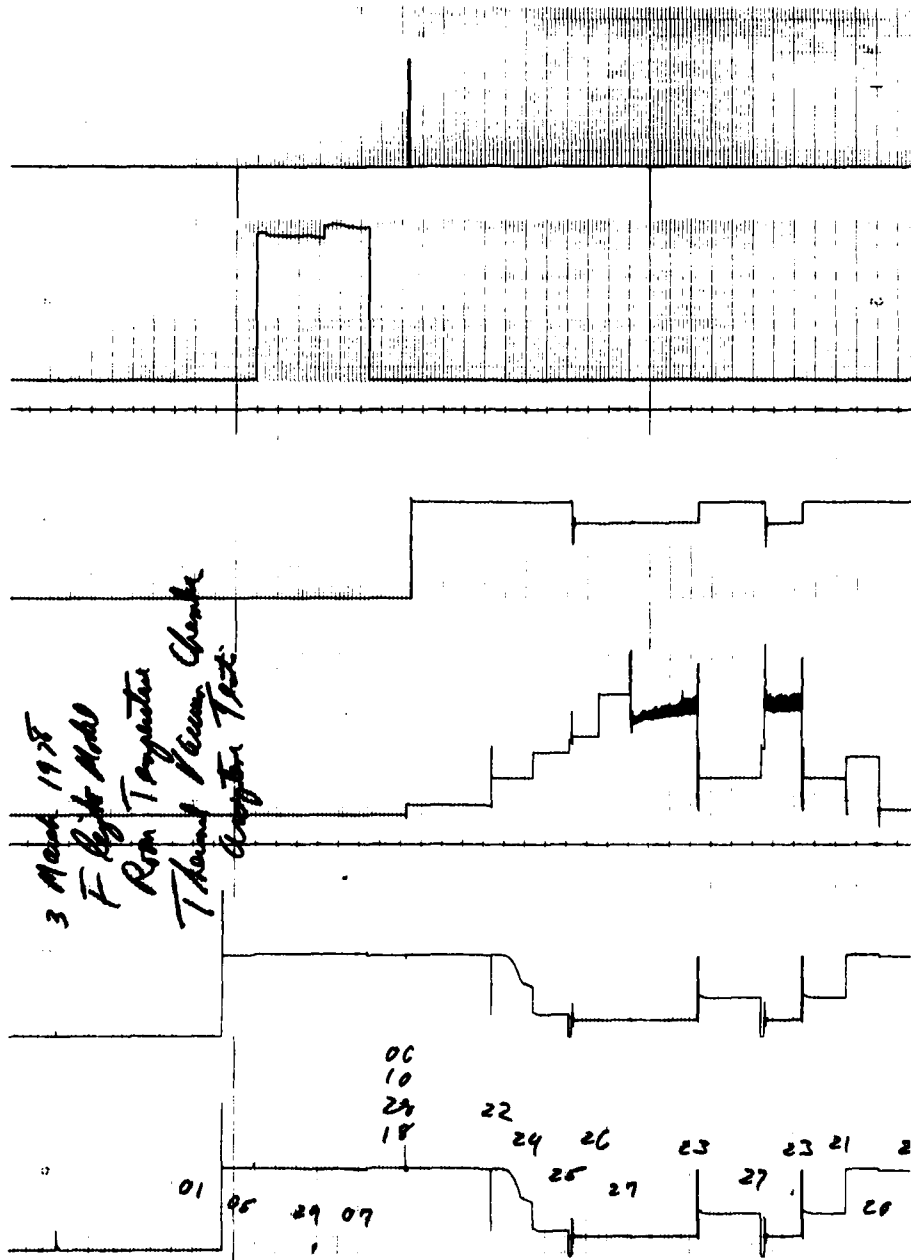


Figure 3. Strip-chart Recorder Output. Channels represented (left to right): net current, neutralizer emission, neutralizer bias voltage, neutralizer heater current, cathode heater current, keeper low voltage. Each graph column is divided into 50 segments (5 V total, 0.1 V per segment). Chart speed is 1 mm/sec. Handwritten numbers indicate commands given

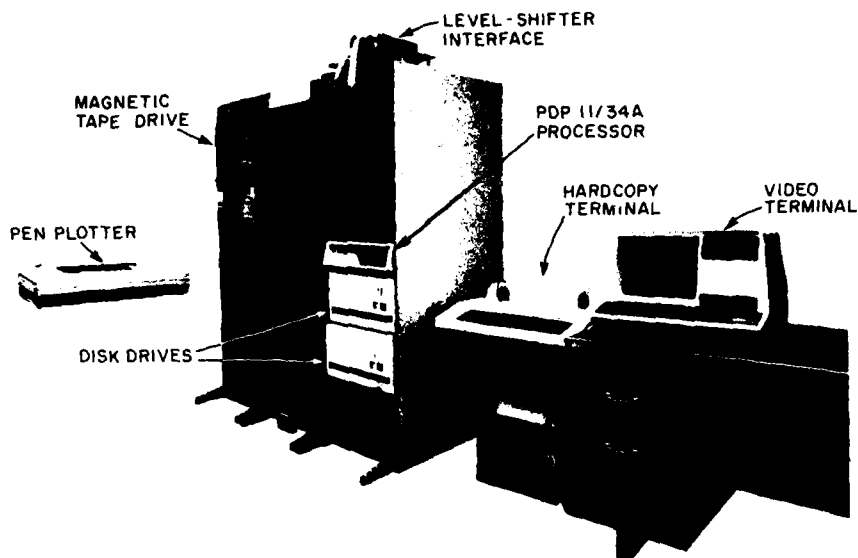


Figure 4. Data Acquisition and Instrument Control System (DAICS)

Computerized data acquisition requires both analog-to-digital signal conversion and sufficient data storage to allow reasonable test lengths at typical sampling rates. The DAICS has a 16-channel A/D converter with a 48-channel multiplexer, which combine to give 64 channels of A/D input. Digitized data is stored on a removable, 5.2 Megabyte disk. This allows storage of up to 5 hr of data on one disk under the present data structure (two words per sample, approximately 75 samples per sec). In addition, the DAICS has an industry-standard magnetic tape drive; stored data can be transferred from disk to tape, allowing data reduction on other systems.

Any comparison of the two methods of data acquisition (strip-chart recorder and A/D conversion) must take into account the basic difference between the two systems. Strip-chart recorders give a continuous record; the analog-to-digital conversion is a sample and hold process. In the A/D conversion process, an analog signal from the SPIBS is amplified and sampled. The signal is held and compared by successive approximation to a second analog signal generated by the A/D converter. The second signal corresponds to a digital value that is stored on disk when the comparison process is complete. One complete sampling and conversion cycle takes 22 m/sec.

Although the A/D converter is capable of digitizing roughly 45,000 samples per sec, the system is limited by the software because of the time necessary to process the instructions for data manipulation and storage. While the effective

frequency response of the DAICS is lower than the analog recorder response (5 - 10 Hz compared to 60 - 100 Hz), the data storage and reduction advantages gained through computerized data acquisition are considerable. The DAICS was designed to give a sample rate at least equivalent to the telemetry system supporting the satellite model SPIBS on board the SCATHA (Satellite Charging at High Altitudes) satellite (16 samples per sec).

The DAICS gives a precision of measurement that is greater than the precision possible with the strip-chart recorders. The A/D converter uses 12-bit digitization, allowing a comparison precise to one part in 4096. The precision is reduced to one part in 1024 because of input noise (approximately 10 mV). This results in measurements of 0.01-V precision, based on the 10.24-V input range of the A/D converter. (Table 3 shows a comparison of the DAICS with the strip-chart recorders).

Table 3. Comparison of DAICS and Analog Strip-chart Recorders. The frequency response is given in different units to emphasize the difference between the two methods of data acquisition

	DAICS (A/D conversion)	Strip-Chart Recorder (analog recording)
Frequency Response	75 samples per sec*	60 - 100 Hz
Precision of Measurement	0.01 V	0.05 V

* Under the present software configuration

The system was designed to provide monitor and control functions. Monitoring is accomplished through real-time display of digitized data on a video terminal, and through command echoing and warning message printing on a hardcopy terminal. The operator can control the experiment by entering commands on the video terminal. The system can also be commanded from the hardcopy terminal, but in this case, the video terminal is bypassed and there is no display of sampled data.

When commands are entered on a terminal, the processor transmits a signal to a 32-channel digital input/output circuit that generates Transistor-Transistor Logic compatible signals (5V). The input/output circuit is connected to a level-shifter interface where the signal is increased to 28 V (as required for SPIBS operation). The DAICS has an additional four channels of D/A output which can be used to control voltage-driven devices, or output data to an X/Y plotter or graphics video terminal. Figure 5 shows the DAICS configuration.

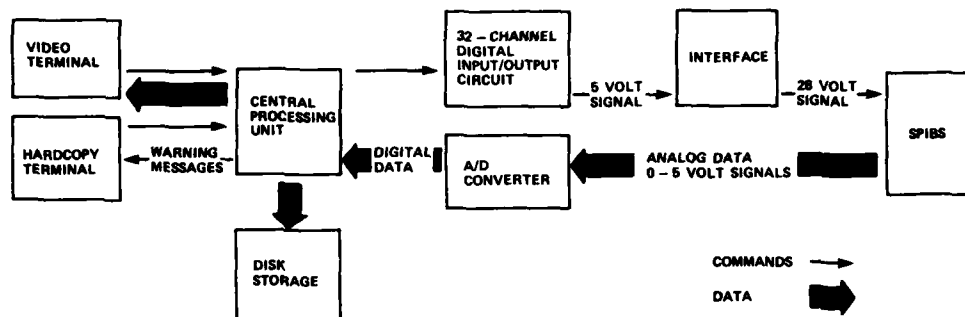


Figure 5. Data Acquisition and Instrument Control System. The system allows the user to monitor the experiment and enter commands at a terminal, while analog data is digitized and stored in real-time

5. SOFTWARE

The operating system (or monitor) chosen for the DAICS is RT11, a single user, real-time system with foreground/background capabilities. The foreground/background monitor allows storage of two programs in memory at the same time. One program is identified as the foreground job, thus giving it priority. Programs can be structured as groups of routines which can be moved back and forth between disk and main memory as required for particular tasks.

The software package developed for the SPIBS experiment is a combination of programs which provides real-time data sampling, command, and control operations, as well as data reduction capabilities. The foreground program, written in assembly language, handles data acquisition and storage, data monitoring, and instrument control functions. The background program, written in FORTRAN IV, handles terminal interaction, and storage and handling of experiment configurations. Although the software was developed for the SPIBS experimentation, it can be used with any experiment that uses low-level analog signals.

A real-time program must be treated differently than the usual linear program. Although the real-time program can be viewed as a set of independent processes operating simultaneously, in actuality the computer can do only one thing at a time. Therefore, only one process can be running at any one time. The processes are then competing for system resources (that is, use of the central processing unit).

Processes communicate with other processes to pass information and to establish timing relationships (synchronization). This job of scheduling and communication between processes is handled by the operating system. In addition to scheduling and communication, the monitor provides other services, including input and output

functions, file manipulation, and data conversion. The monitor itself consists of many independent processes which are competing with the application program for use of the central processing unit.

Within the framework established by the foreground/background monitor, the operating system uses a three-level hierarchy to schedule processes: mainline, completion, and interrupt. The mainline has the lowest priority, performing display and command reception functions. The completion routines can interrupt the mainline process; these routines interpret instructions, synchronize processes, and update data structures. Interrupt routines, such as those controlling sampling and conversion, have the highest priority. Interrupts are synchronous (initiated by the program) or asynchronous (triggered by an external device, such as the system clock or an external event). This scheduling system allows a complex system of tasks to be executed in real-time.

5.1 Experiment Control

The software has been designed to allow a person with minimal programming experience to control the experiment. Interactive processing gives direct control over the experiment from a terminal. A series of simple commands directs the major processes; command definitions are available through a "HELP" command (Figure 6). The researcher can define experiment parameters, and then generate commands as required to operate the instrument while monitoring experiment conditions and results.

The program allows a great deal of flexibility in experiment design. It was designed to use a default experiment configuration automatically, but the configuration can be changed. Information given in response to a series of questions describes the experiment parameters (Figure 7): number and labeling of analog channels to be sampled; sampling intervals for each channel; and warning levels for sampled input. New information given for experiment parameters does not change the default file. If the parameters are changed, the new configuration can be saved in a separate file that can be retrieved for later use.

5.2 Data Acquisition

Analog data is sampled, digitized, and stored on disk in real-time. This process is the result of a number of foreground routines which interact to control the A/D converter and the data transfer. During each sampling cycle, the software is capable of accepting and manipulating digitized values for all of the channels. Figure 8 shows the processes that control sampling and data storage.

```

ANY CHANGES TO COMMAND-AD FLAGS INVOLVING THIS CHANNEL? N
SC4)HELP

Commands available:
STA Start sampling
STO Stop sampling
C External command
END End session
CHA Define A/D channel
CON Show configuration
DEF Define block command
SAV Save configuration
GET Get configuration

For help on each item, type HELP item

SC4)HELP CHA

CHA n where n is a number (64 or a 1-3 letter mnemonic)
Define a configuration for A/D channel n, including compound flags.
SC4)

```

Figure 6. Video Terminal Display: Software Commands. The "HELP" command produces a listing of the acquisition, monitoring, and control software commands; the prompt "SC4)" refers to the satellite model particle beam system. The "HELP" command used with a software command produces the command definition.

```

SC4)CHA 15

DO YOU WANT TO REMOVE THIS CHANNEL? (Y OR N): N
SAMPLE INTERVAL, MSEC OLD: 5000 NEW? (Y OR N): N
DISPLAY INTERVAL, SAMP OLD: 1 NEW? (Y OR N): N
RED HIGH LIMIT (MV) OLD: 5120 NEW? (Y OR N): Y
ENTER NEW VALUE: 4000
RED LOW LIMIT (MV) OLD: 1500 NEW? (Y OR N): N
YELLOW HIGH LIMIT (MV) OLD: 5120 NEW? (Y OR N): Y
ENTER NEW VALUE: 3000
YELLOW LOW LIMIT (MV) OLD: 1600 NEW? (Y OR N): N
MNEMONIC OLD: THP NEW? (Y OR N): N
NAME OLD: TEMPERATURE NEW? (Y OR N): N

ANY CHANGES TO COMPOUND FLAGS INVOLVING THIS CHANNEL? N

ANY CHANGES TO COMMAND-AD FLAGS INVOLVING THIS CHANNEL? N
SC4)

```

Figure 7. Video Terminal Display: A/D Channel Definition. Interactive processing allows the researcher to define the parameters for data acquisition.

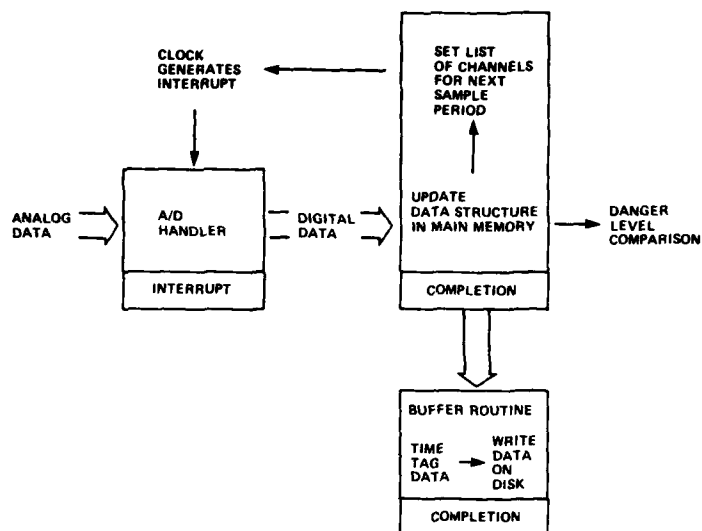


Figure 8. Foreground Processes For Sampling and Data Storage. Once sampling is initiated from the terminal the data conversion-and-storage loop will continue until sampling is stopped from the terminal. The programmable clock calls the A/D handler, a software routine that controls the A/D converter. Analog input is digitized, then a second routine transfers the digitized data to main memory and calls a subroutine that sets the list of channels for the next time. The data in main memory is time-tagged and written on a disk, and compared to values established for danger levels

When testing is started, all channel values are recorded immediately. After the first set of samples, each sampling and digitization cycle is initiated by a programmable clock, at intervals according to user specifications. The A/D converter is directed by a monitor-controlled interrupt routine (the A/D device handler). When the digitization is finished, a completion routine updates the data structure in main memory. The data is transferred to a buffer (temporary storage), time-tagged, and then written on a disk. Once the data structure has been updated, the channels are set for the next sampling period, and the central processing unit is set for the next conversion.

The current program configuration can process up to 32 channels of analog data. The present experiment configuration uses 22 channels: 18 channels come directly from the SPIBS; 4 channels are connected to particle detection equipment in the vacuum chamber. Figure 9 shows a listing of the channels and channel parameter.

CHA	SIN	DRA	RHI	RLO	YHI	YLO	MNE	NAME
0	100	10	5120	-100	5120	-75	IBM	BEAM CURRENT
1	5000	1	5120	-100	5120	-75	VBM	BEAM VOLTAGE
2	1000	1	5120	-100	5120	-75	IDS	DISCH. CURRENT
3	1000	1	5120	-100	5120	-75	VDS	DISCH. VOLTAGE
4	5000	1	5120	-100	5120	-75	IKP	KEEPER CURRENT
5	5000	1	5120	-100	5120	-75	IKV	KEEPER H.V.
6	1000	1	5120	-100	5120	-75	KLK	KEEPER C.V.
7	1000	1	5120	-100	5120	-75	CTH	CATHODE HEATER
8	5000	1	5120	-100	5120	-75	ACC	ACCEL. CURRENT
9	5000	1	5120	-100	5120	-75	DEC	DECEL. CURRENT
10	5000	1	5120	-100	5120	-75	NHT	NEUT. HEATER
11	5000	1	5120	-100	5120	-75	BIA	NEUT. BIAS V.
12	100	10	5120	-100	5120	-75	NEL	NEUT. EMISSION
13	100	10	5120	-100	5120	-75	NET	NET. EMISSION
14	5000	1	5120	-100	5120	-75	PRE	PRESSURE
15	5000	1	5120	1500	5120	1600	TMP	TEMPERATURE
16	5000	1	5120	0	5120	0	IPF	RPA CURRENT
17	5000	1	5120	0	5120	0	VPP	RPA VOLTAGE
20	500	2	300	-240	120	60	GND	RPA GROUND
21	500	2	5120	-5122	5120	-5122	RPA	RPA ELECTROMETER
22	500	2	5120	-5122	5120	-5122	RTV	RETARDING VOLTS
24	500	2	3500	300	3000	850	ARC	RPA POSITION

Figure 9. Video Terminal Display: SPIBS Experiment Configuration. Channel parameters for ion beam system output and particle detection equipment: channel number, sample interval (milliseconds), display rate (samples averaged/second), red (danger) high level (millivolts), red low level (millivolts), yellow (caution) high level (millivolts), yellow low level (millivolts), mnemonic, channel description

Sampling rates are specified by the researcher. The range of rates extends from one sampling period every 23 sec to one sample every 22 msec. The maximum sampling rate is dependent upon the number of channels operating. Thus, when operating with a fully loaded configuration, the fastest rate possible is one every 50 msec. Table 4 shows the minimum sample interval according to the number of channels operating.

5.3 Monitoring

The DAISC gives the researcher more experiment control than was allowed using other methods. Experiment conditions, such as instrument output and environment characteristics, can be monitored from a video terminal. The system also provides for an audio-visual warning system that is activated according to pre-set conditions.

Table 4. Minimum Sample Intervals According to Number of Channels Operating. The table indicates intervals required to insure storage of all data; shorter intervals will result in some data loss

No. of Channels	Sample Interval (msec)
1	45 45
5	50 50
10	50
15	60
20	70
25	70
32	70

Figure 10 shows the video terminal display during sampling. The upper half of the screen is dedicated to real-time display of analog signals. Channels are identified by mnemonics. The integer values represent millivolt measurements of sampled, telemetry input signals. As with sampling rates, the rate of display update can be specified by the operator. The fastest rate of update is once per second; the values displayed are averages taken over the update period. In addition, the elapsed time is shown in hours, minutes, and seconds. The lower half of the screen shows prompts and commands.

Foreground and background processes combine to provide the monitoring capabilities (Figure 11). The operator can specify caution and danger levels for the analog output from the instrument. Sampled, digitized data is compared to these values and stored in a buffer as part of the foreground processing. Any warnings required as a result of the comparisons are also stored in the buffer. Background processing displays the data and also prints out warnings as necessary.

Warning messages (flags) are printed on the hardcopy terminal and an alarm sounds when caution or danger levels are reached (Figure 12). The program also prints out commands generated from the terminal. The warning system has been particularly valuable for the SPIBS experimentation. For example, the temperature of the power processor assembly is critical. Using earlier experiment techniques, it was necessary for a person to monitor the temperature constantly, in addition to the other tasks required in running the experiment. Computerized monitoring calls attention to experiment conditions as required, leaving personnel free for other experiment duties.

Additional flag comparisons can be invoked by using compound AD/AD flags or compound AD/command flags. The AD/AD condition allows the researcher to specify output voltage levels for two channels at the same time: if both levels are reached, a message is printed. The AD/command condition disables a particular command when the specified channel reaches its designated level.

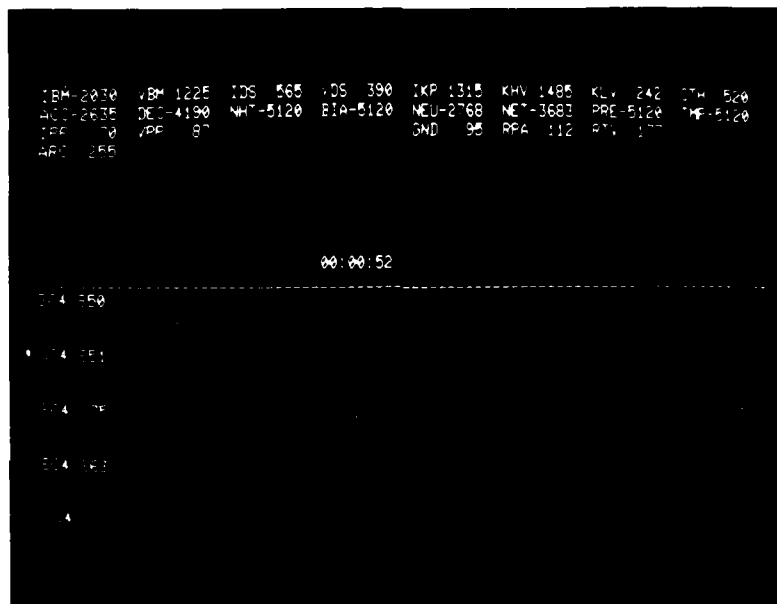


Figure 10. Video Terminal Display: Sampling Display. The data acquisition and instrument control software was written to allow the researcher to monitor the experiment and control the instrument from the same terminal. Channel mnemonics, integer values corresponding to telemetry input voltages (millivolts), and elapsed time are displayed on the upper half of the terminal screen. The lower half shows software prompts ("SC4>") and commands

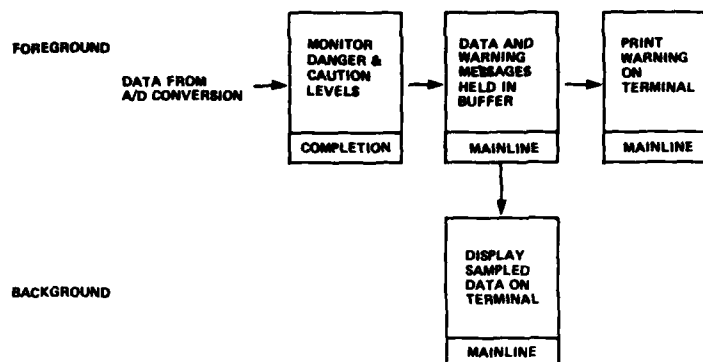


Figure 11. Foreground and Background Processes for Monitoring and Display Functions. The foreground/background monitor allows sampling and danger level comparisons to continue in foreground processing, while the background process displays accumulated data and messages

```
00:06:18.000 CAUTION: KLV
00:06:19.000 DANGER: KLV
00:06:25.000 DANGER: IFF
00:06:25.000 DANGER: VFF
```

Figure 12. Hardcopy Output: Warning Messages. The monitor processing includes comparisons between sampled data and predetermined danger levels, and subsequent printing of warning messages. The output shows time, warning level, and channel mnemonic

5.4 Instrument Control

The system gives the researcher a quick, reliable, and flexible method of instrument control. Earlier methods involved simpler devices which did not give any indications that commands had been issued. Computerized instrument control is accomplished through a series of commands that are entered, and echoed, on a terminal. The commands used in the software for the ion beam experiments were developed as part of the SPIBS hardware design (Figure 13).

COMMANDS

850	SPIBS	SYSTEM POWER ON
851	SPIBS	SYSTEM POWER OFF
852	SPIBS	GAS VALVE OPEN
853	SPIBS	GAS VALVE CLOSED
854	SPIBS	ION BEAM ON
855	SPIBS	ION BEAM OFF
856	SPIBS	CATHODE CONDITIONING
857	SPIBS	CATHODE PREHEAT
858	SPIBS	1KV BEAM ENERGY
859	SPIBS	2KV BEAM ENERGY
860	SPIBS	KEEPER OFF
861	SPIBS	NEUTRALIZER # 1
862	SPIBS	NEUTRALIZER # 2
863	SPIBS	NEUTRALIZER HEATER ON
864	SPIBS	NEUTRALIZER HEATER OFF
865	SPIBS	HIGH VOLTAGE OFF
871	SPIBS	BEAM & NEUT. 0.3MA CURRENT
872	SPIBS	BEAM & NEUT. 1.0MA CURRENT
873	SPIBS	BEAM & NEUT. 2.0MA CURRENT
874	SPIBS	NEUTRALIZER 0.008MA CURRENT
875	SPIBS	NEUTRALIZER 0.02MA CURRENT
878	SPIBS	NEUT. BIAS POSITIVE & ON
879	SPIBS	NEUT. BIAS NEGATIVE & ON
880	SPIBS	NEUT. BIAS OFF
881	SPIBS	NEUT. BIAS 10V ENERGY
882	SPIBS	NEUT. BIAS 25V ENERGY
883	SPIBS	NEUT. BIAS 100V ENERGY
884	SPIBS	NEUT. BIAS 500V ENERGY
885	SPIBS	NEUT. BIAS 1KV ENERGY

Figure 13. Software Instrument Commands. The SPIBS software allows the operator to control the instrument from a terminal using single commands (S50, S51, and so on)

Before the DAICS was installed, commands were issued relatively slowly, one after another. The SPIBS software allows the researcher to control the instrument with single or block (grouped) instructions (Figure 14) using short, coded commands. A command is processed in both the foreground and background programs (Figure 15). The software provides a command pulse length (100 msec) that meets the standard established for satellite command systems.

5.5 Data Reduction

The DAICS allows rapid, accurate data reduction. This computerized data reduction provides a wide range of possibilities which can be accomplished in a much shorter period of time than possible through manual reduction of strip-chart recorder data. Instrument output can be processed through a series of interactive programs which provide plotting, calibration, printing, and data transfer functions.

```

888 SPIBS INITIALIZE & OFF   s/c 11
    853
    851
    855
    858
    861
    864
    872
    880
    881
    860
    865
889 SPIBS EXPELLANT INITIALIZE s/c 6
    852
    WAIT 4
    853
894 SPIBS NEUT. INITIALIZE & HEATER ON s/c 5
    854
    860
    865
    879
    863

```

Figure 14. Block Commands. The operator can combine single commands, and other block commands, and implement them as a group by using short, coded commands. "s/c n" refers to the number of commands in the block (step count, number of commands). "wait 4" results in a pause of 4 sec before implementing the next command in the block

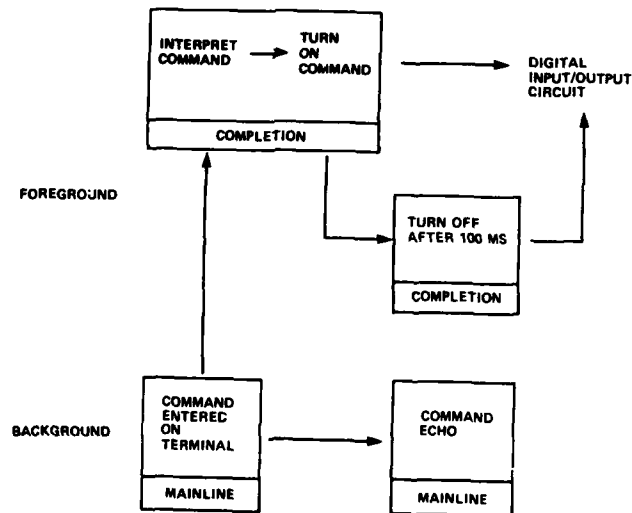


Figure 15. Foreground and Background Processes for Instrument Control. A command entered at the terminal causes the transmission of a 100 msec pulse to the digital input/output circuit

The plot program will produce graphs of sampled data on a video graphics terminal or a pen plotter. One or two channels can be plotted against time. The time scale can be expanded or condensed to represent the entire test period or a small portion of it. In addition, on the pen plotter, one channel can be plotted against the other. Scaling is either automatic or user-specified.

Data can be plotted as uncalibrated instrument output (telemetry voltages), or can be converted to engineering units using calibration files. The calibration program allows the researcher to define calibration curves for the analog channels. Other programs print data on a line printer and transfer data from disk to magnetic tape for processing on other systems.

Appendix E contains examples of data reduction programming output.

6. CONCLUSION

A computerized Data Acquisition and Instrument Control System is being used for the Satellite Positive Ion Beam System experimentation. In changing from an analog recording system to an analog-to-digital conversion system, some accuracy has been lost, but greater experiment control has been established. The frequency response of the DAICS is somewhat lower, and its precision of measurement, somewhat greater than the capabilities of the strip-chart recorders. However, the reliability and flexibility of the computer system, combined with the instrument control, data storage, and data reduction capabilities, have significantly expanded the scope of the SPIBS laboratory experimentation. In addition, the system has the potential for development.

Appendix A

DAICS Hardware

Acquired from Digital Equipment Corporation:

PDP 11/34A Processor (Extended Instruction Set, and memory mapping)

32 k words Solid State Memory (MOS) with parity

Programmable Clock (KW11-K)

A/D Input (64 channels)

- 16 channel A/D converter (AD11-K)
- 48 channel multiplexer (AM11-K)

Analog Output

- 4 channel D/A converter (AA11-K)

Digital Input/Output (32 channels)

- two 16 bit digital input-output (DR11-K)

Removable Disk Storage

- two 5.2 M byte disk storage (RL01)

Magnetic Tape Drive (TME11-EA)

- 9 track, 800 bpi, 45 ips

Hardcopy Terminal - DECwriter (LA-36)

- 300 baud

Video Terminal - DECgraphic Scope (VT-55)

- 9600 baud

Instrumentation Buss Interface (IB11)

- for external instrument control and data collection
(IEEE-488-1975 buss)

Supplementary Hardware:

Hewlett Packard Digital Plotter (9872S)

Level-shifter Interface

- circuitry designed to increase TTL level signals (5 V)
- discrete command pulse level (20 V)

Appendix B

Data Reduction

This appendix contains examples of output from the plotting and printing programs designed for the Data Acquisition and Instrument Control System. All of the programs use interactive processing to define the parameters for the data processing.

Figures B1 through B4 and B6 through B8 show output from the plotting program. Figure B5 shows strip-chart recorder output for comparison with computer plots (Figures B6 through B8). Figure B9 shows output from the data printing program.

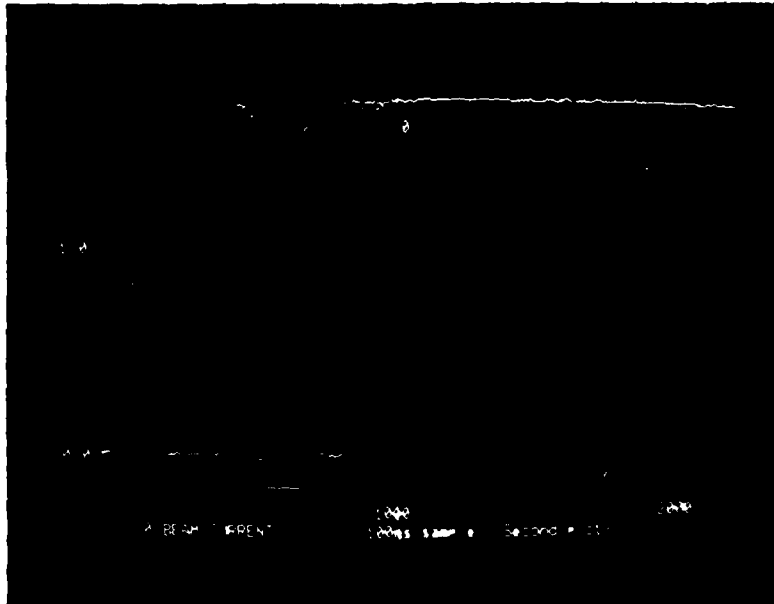


Figure B1. Video Terminal Display Showing a Calibrated Plot of One Channel (beam current, mA) Plotted Against Time. The plot program first produces output on the video terminal, then on the pen plotter

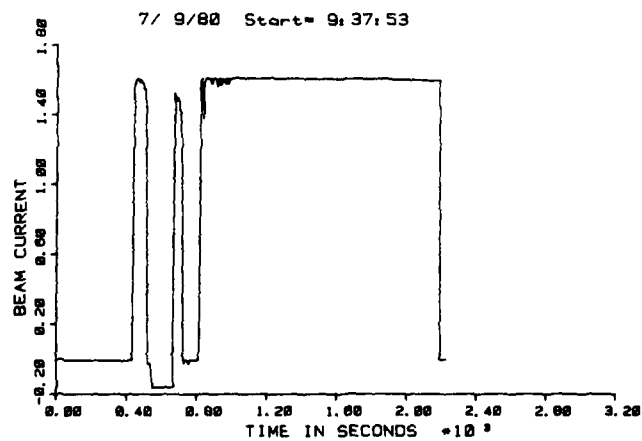


Figure B2. Calibrated Pen Plot of One Channel (beam current, mA) Against Time. (Same event as Figure B1)



Figure B3. Video Terminal Display of Calibrated Plot of Two Channels, Beam Current (mA) and Net Emission (μA), Plotted Against Time

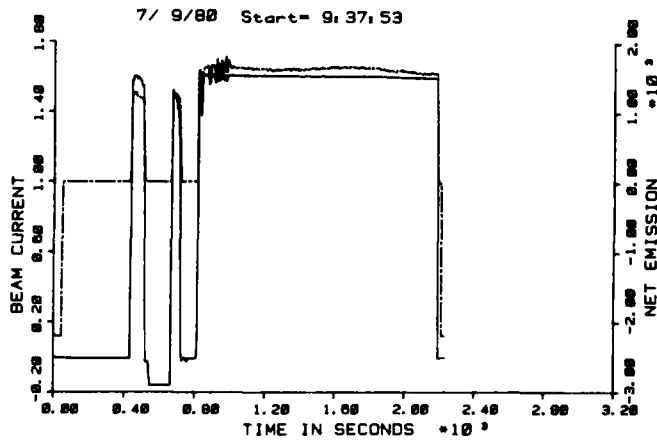


Figure B4. Calibrated Pen Plot of Two Channels, Beam Current (mA) and Net Emission (μA) Against Time. Beam current is represented with solid line. (Same event as Figure B3)

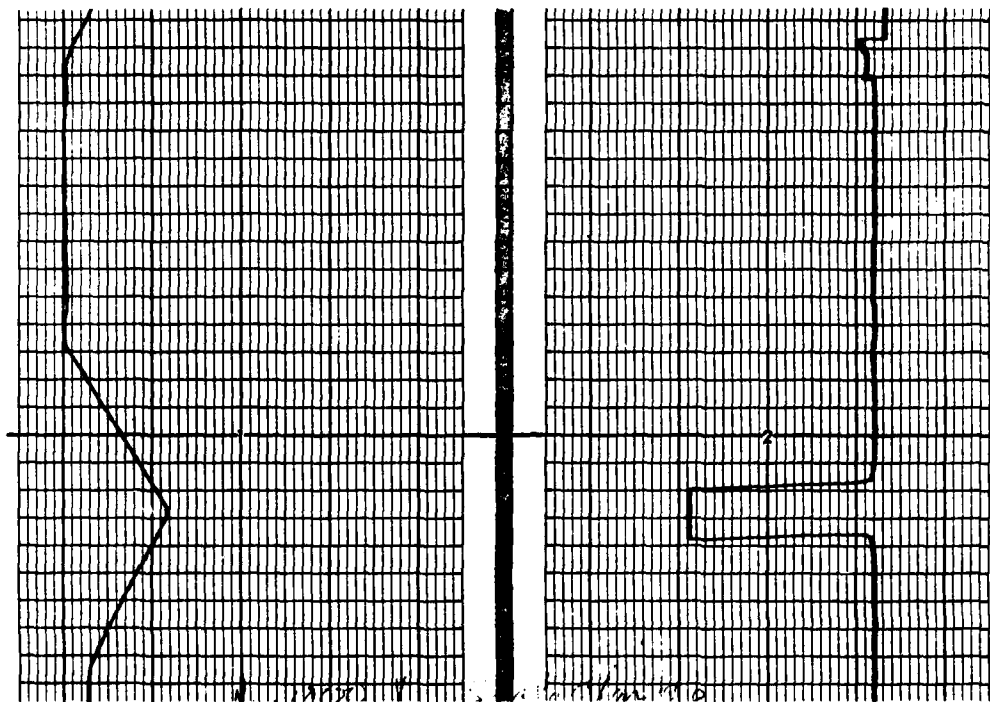


Figure B5. Strip-chart Record of Two Channels. (Left to right) potential across a retarding grid on a Retarding Potential Analyzer (RPA), and RPA electrometer. Each channel is recorded relative to the analog input range of 0 to 5 V; the divisions represent 0.1-V segments. Chart speed is 1 mm/sec. Once recorded on the strip-charts, data had to be converted to engineering units and graphed

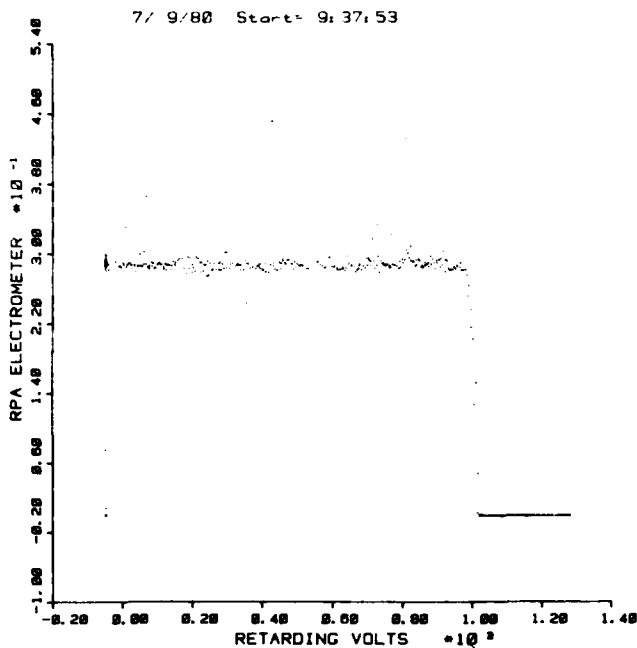


Figure B8. Pen Plot: One Channel (retarding voltage) Against a Second (RPA electrometer). (Same event as represented in Figures B6 and B7)

CHANNEL NUMBER TIME	0 IBM	1 VRM	4 IKP	15 TMP	21 RPA
710.000	1.35	948.	138.	34.7	2.944E-04
711.000	1.22	948.	138.	34.7	2.640E-04
712.000	1.13	948.	138.	34.7	2.584E-04
713.000	1.15	948.	138.	34.7	3.505E-04
714.000	1.13	948.	138.	34.7	3.661E-04
715.000	1.10	948.	85.2	34.7	4.126E-04
716.000	1.11	948.	85.2	34.7	4.912E-04
717.000	0.228	948.	85.2	34.7	1.420E-04
718.000	0.187	948.	85.2	34.7	1.024E-04
719.000	0.194	948.	85.2	34.7	8.509E-05
720.000	CAUTION: CHANNEL 11		BIA		
720.000	-6.160E-03	948.	88.9	35.9	0.000
728.000	CAUTION: CHANNEL 0		IBM		
728.000	-1.628E-02	948.	89.2	37.1	0.000
728.100	DANGER: CHANNEL 0		IBM		
728.200	CAUTION: CHANNEL 0		IBM		
728.300	DANGER: CHANNEL 0		IBM		
728.400	CAUTION: CHANNEL 0		IBM		
729.000	-2.134E-02	948.	89.2	37.1	0.000
729.600	COMMAND S S55				
730.000	-2.365E-03	0.000	0.000	34.8	0.000
731.000	-4.895E-03	0.000	0.000	34.8	0.000
732.000	-3.630E-03	0.000	0.000	34.8	0.000
733.000	-3.630E-03	0.000	0.000	34.8	0.000
734.000	-4.895E-03	0.000	0.000	34.8	0.000
735.000	-4.895E-03	0.000	0.000	34.9	0.000

Figure B9. Calibrated Hardcopy Output From the Data Printing Program. The operator can specify the number of channels to be printed (up to 10), the total time period to be processed, the time interval between data points to be processed, and printing of commands and warnings

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