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## RESEARCH ESTABLISHMENT

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by

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June 1976

ISBN 0 642 99753 5

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ABSTRACT

A PDP9L computer is used as the basis for a multistation pulse height analysis system. Each station which is equipped with an analog-to-digital converter, a display and a keyboard-printer can perform the basic operations associated with a commercial hard-wired system. The stations are independent of one another but two or more accumulating or displaying simultaneously result in a slight increase in analog-to-digital converter dead time. The keyboard-printer operates in conversational mode with no output forthcoming if incorrect characters are entered. System procedures are initiated from the station keyboard to control the display, accumulate, integrate, and read and write functions as flexibly as possible without excessively increasing the program-to-data ratio for core usage.

This system was designed to enable software to be modified when different procedures become necessary, and to enable adaptation of the available equipment to other modes of accumulation and display.

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*This report was originally published as a Thesis for the Degree of Master of Engineering Science in the School of Electrical Engineering at the University of New South Wales, February 1971.*

National Library of Australia card number and ISBN 0 642 99753 5

The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA–INIS–12 (INIS: Manual for Indexing) and IAEA–INIS–13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

ANALOG–TO–DIGITAL CONVERTERS; COUNTING TECHNIQUES; DATA ACQUISITION SYSTEMS; DISPLAY DEVICES; MULTI–CHANNEL ANALYZERS; ON–LINE MEASUREMENT SYSTEMS; OPERATION; PDP COMPUTERS

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## 1. INTRODUCTION

When radioactive particles were first detected, the prime aim of the experimenter was to determine the number of counts recorded in a given time to give a measurement of source activity. However, when the radiation emitted from a source is used to determine the chemical components of the source, other measurements as well as a count rate are required. The most obvious of these are a measurement of the energies of the incident particles wherever possible and a tabulation of the number of counts received in a defined energy band. These are measured using window discriminators, or 'single channel analysers', which allow only those events above the lower discriminator and below the upper discriminator to be recorded. A spectrum of the incident particle energies can thus be built up by sweeping the window through the required energy range. Data analysis using this type of equipment is slow, since reasonable statistics must be established before moving to the next channel in the spectrum. Multichannel analysers, developed to overcome the long counting times, are able to accumulate a whole spectrum simultaneously, the overall result being a number of counts in a series of scalers.

About twenty years ago, multichannel pulse height analysers were 'discriminator' analysers which incremented each count channel whenever an input signal fell within preadjusted voltage limits. Each count channel had a scaler associated with it, the contents of these scalers indicating the distribution of pulse amplitudes occurring during the experiment.

Wilkinson [1950] introduced the concept of digitising each input pulse and incrementing a counter corresponding to the digitised number, the selection being performed by digital rather than the more complex analog circuitry. Once the pulse had been digitised, a digital computer could be used to count and store the pulse information, instead of a series of scaling channels. The computers used hard-wired, non-flexible units which performed automatic curve plotting, automatic digital readout, automatic display generation and, in some instances, internal data reduction.

The conversion methods used to digitise the input pulse height usually operated with a linear ramp, as is the case with a large majority of present day analog-to-digital converters (ADC), while the techniques used to store, retrieve and modify the separate channel data underwent rapid changes until the advent of coincident current magnetic core memories.

The large increase in the data handling capabilities of the multichannel analyser over the last decade, with the corresponding increase in the resolution of the associated ADCs, has enabled much more precise spectra to be recorded. The increase in analyser resolution has barely kept pace with the development of radiation detectors. This is due mainly to the halide detecting crystals being superseded by solid state detectors, the most recent being lithium-drifted germanium devices. These are capable of very fine line widths but cannot be used outside a laboratory environment. The resolutions of these detectors have improved from about five per cent to one in one thousand. As a result, multichannel analysers have correspondingly increased channel capacities from approximately one hundred to nearly ten thousand with the associated converters improving to maintain a one-channel resolution. Some typical spectra using sodium iodide and lithium-drifted germanium detectors are given in Appendix A.

The scope of the conventional pulse height analyser is easily handled by a small on-line computer with an ADC and a display interfaced to the main processor. When a small computer is used as the basis for a system, a large gain in flexibility is obtained although not without some slight disadvantages. The small computer can be reprogrammed to allow for changing fields of experiment and different operator requirements.

The main advantage of the small computer is that it is capable of operating many devices without too much degradation of device performance. This capability can be used to operate duplicate sets of equipment such that two or more subsystems can be set up which basically perform identical operations for different users. The small computer can be programmed and interfaced such that each subsystem seemingly operates independently of the others, i.e. without any apparent changes in operation or performance.

The system described here was first constructed with the basic 4096 word processor to operate two pulse height analysis stations with 1024 and 1536 channels available to their respective data areas, but it has since been expanded to three stations using an 8192 word processor.

Extra stations will be added as the need arises, and no severe limitations are envisaged up to about five users.

## 2. CONVENTIONAL PULSE HEIGHT ANALYSERS

Multichannel analysers generally come in three forms:

- for time-of-flight analysis,
- for general counting and control, and
- for pulse height studies.

These basic groups generally need very similar memory logic and control and only require different converters to produce the digital data word and appropriate control signals. In fact, many analysers have the capability of operating in each of the basic groups, by using either a mode switch or separate plug-in converters.

Experiments in the above classes require an instrument that can accept, store, refine and present large quantities of data because of the statistical nature of the experimental readings. When the system capabilities are expanded, the cost of the system is comparable to and, in most cases, higher than those systems using a cheap on-line computer such as the PDP8, whereas larger computers can only be justified by expanding the required facilities.

### 2.1 Basic Pulse Height Operation (Figure 1)

When an event occurs in the source, it may be detected by the detector and, after subsequent amplification shaping, etc., it will appear as a pulse input to the ADC. Here, the pulse height is converted to a digital number and the subsequent parallel binary information is sent to the memory control unit. This digital information is recognised by the control unit as corresponding to one of the values assigned to a channel (data word) in the memory unit. The contents of this channel are read out, modified by one and restored to the channel. At the completion of this operation, the ADC is cleared and readied for the next detector pulse.

After an experiment has been analysed for a sufficient time, a histogram representing the spread in pulse heights has been accumulated. This histogram or spectrum can then be displayed on the cathode ray tube or the contents of each channel printed out on the typewriter or page printer. In the basic configuration, if further processing of the results is required, these are punched up as data for a suitable computer. If a permanent copy of the displayed spectrum is required, it can be photographed or replotted from the typewritten copy.

Usually an experiment is set up using the accumulate and the display modes and, when ready, the analyser is then switched to the accumulate mode for a predetermined preset time. When this period has elapsed the results can be examined via the display and, if satisfactory, printed out. If a more accurate spectrum is required there are various methods of allowing for background, the most common method being to count in a subtract mode for an equivalent accumulate time but with the measured source removed from the vicinity of the input detector.

### 2.2 System Expansion

The basic hard-wired pulse height analyser can be expanded in many ways to include numerous facilities some of which are only pertinent to particular users. The usual extensions are:

1. A fast paper tape handling system used to store spectra on perforated paper tape and to retrieve these data when required.
2. An XY plotter capable of producing an accurate graphical spectrum suitable for further measurements.
3. The facility to integrate the total counts under a peak or in subgroups enabling relative comparison of intensity and subsequent printout of this information.
4. Shifting of memory subgroups from one position to another for temporary storage and operator comparison of spectra.
5. Automatic modes whereby repeated runs can be set up and executed with minimal operator intervention.
6. Display of markers on the visual display to facilitate peak identification, etc.

These extended features are available on most expanded hard-wired pulse height analyser systems and as such should be available on any replacement system.

## 3. SYSTEM OPERATION

### 3.1 General

The overall system consists of the computer and three pulse height analysis stations. These stations are situated at approximately 7, 12 and 70 m respectively from the actual computer. These situations are variable with the limitation that extra driving capability is required for stations further than 30 m from the computer, *i.e.* the most remote station above.

Each station is completely independent of any other except for a slight buildup of dead-time delays for ADC operation. Each station operates on a peripheral basis to the central processor and consists of the following necessary equipment:

(a) A teletype ASR33 used for typing in commands and for printing of spectra and associated data at ten characters per second. These units can also be used to punch and read perforated paper tape.

(b) An ADC capable of 10-bit conversion. The actual converter interface is capable of operating a 12-bit converter if required.

(c) A cathode ray oscilloscope used to display the selected spectrum or part thereof. The X and Y voltages supplied are capable of driving an XY plotter when appropriate commands are used.

(d) A spectrum capacity that is governed by the requirements of the particular station, the total capacity being 6144 channels. These may be split into units of 512 channels subject to certain boundary conditions. Each channel is capable of storing up to 262 143 counts before overflow occurs.

#### 3.1.1 Station operation

Each station is capable of executing a large number of commands, the command repertoire being governed by user requirements which themselves are dependent upon the facilities available to an expanded hardwired system user (see Section 2.2). All the commands available to the station user can be implemented at the keyboard which operates in conversational mode. It is not necessary for the user to operate the computer except for system start-up.

When a station is not being used or has completed the current task, the program controlling the station sits in a waiting loop waiting for a job request. This request must come from the teletype as a valid command sequence. The control program will still operate any display or repetitive operation while it is in the waiting loop. The waiting loop will be entered during execution of particular commands and is due to the following conditions:

1. Waiting for a new command to be entered at the ASR33 keyboard.
2. Waiting for data pertinent to the command to be entered at the ASR33 keyboard.
3. Waiting for an experiment to finish, i.e. waiting until the set live-time for the experiment has expired.

The above three cases can only be determined by knowing what commands have been entered in at the keyboard before entering the waiting loop. Also at the completion of the current task, the teleprinter will perform a carriage return linefeed which enables the operator to determine whether the last task is complete or waiting for data or count.

#### 3.1.2 Analog-to-digital operation

Each station uses a commercial ADC (ND1100 series) which is capable of 1024 channel range (10-bit). The actual conversion range of the converter can be set by using the front panel switches provided. The range accepted by the station is controlled by the station hardware which is governed by teletype command. The actual conversion range of the converter is completely independent of the station but obviously if the conversion range is smaller than the station range then a full spectrum will not be obtained. For most efficient operation, the conversion range and the station range should be identical but for slow count rates the conversion range can be set to the maximum as dead-time effects will be small.

Experiment timing for each ADC is controlled using a live-time clock. This clock operates from a real-time clock of 1000 Hz which is inhibited whenever the ADC converter is busy. This method of live-time generation relies on the random arrival of detector pulses from the source and is only accurate to within statistical tolerances.

Longer live-time runs will be subject to much less error than shorter runs. If the input detector signal is not random and has a periodic nature then the live-time measurement is pointless and may be totally inaccurate.

#### 3.1.3 Display operation

Each station uses a commercial display (BWD205) which has an 8 x 10 cm screen (this is a function of the display and not the station display hardware). The display is operated as a point display with the X and Y axes both having a resolution of 10 bits, i.e. 1024 points full scale.

The station scales for display control the full scale ranges used for the X and Y data, i.e. channel number and contents. The display is capable of being adjusted independently of the station if extra expansion is required, The intensity of each spot can only be adjusted by the display controls and is independent of the station.

A spectrum is displayed in two phases, the actual spectrum display of channel number versus channel contents over which is superimposed the marker display consisting of two vertical lines. These markers are used to identify and subgroup particular sections of the overall spectrum. Control of marker positions is a function of the station only. The section between the markers may be expanded, etc. when greater detail of the selected section is required.

3.2 Command Formats and Function

Commands and data may be entered in two ways, manually at the keyboard of the ASR33 teletype, or at the associated tape reader. When a program is running it can only be interrupted from the keyboard but will start reading tape when it returns to the waiting loop. These two input media are indistinguishable to the computer. Commands begin with a slash (/), so when a slash is received, the computer will try to read two characters off tape to complete the command format regardless of whether the slash is initiated from the keyboard or from the reader. NOTE if a data tape is in the reader, then the reader should be switched off before typing a slash on the keyboard.

All commands are composed of three characters: a slash, which denotes a command, followed by two alphabetic characters which must be available within fifteen seconds of receipt of the slash, otherwise the command will be treated as invalid. After the command is checked against the current table of instructions it will be printed out if valid and ignored if not. When a valid command is received, the program, after setting and resetting the program flags required, will pass control to the address specified in the command table. The particular program sequence will be performed and, eventually, the computer will end up in a waiting loop, waiting for the next command.

There are two main types of command, main program and interrupt program commands. Both are confirmed by being typed out but only main program commands terminate the existing program. Interrupt commands are used to set and reset flags which are examined by the main program and supervisor loops, these flags controlling input, displays, etc.

### 3.3 Data Formats

Various main and interrupt programs require data input before proceeding with the command execution. The data required will always be in integer format with normal limits of -131072 to +131071. In some instances numbers up to 262143 will be valid but only when a data block is being read back into memory. Numbers exceeding the above limits will be truncated and in most cases will differ from the intended input.

All numbers when typed and checked must be terminated by a colon before being accepted by the computer as valid. If a number is incorrectly entered on the keyboard, the entire number field (back to the last colon) is cleared if the 'rubout' key is pressed before typing the terminating colon. Once this colon has been typed in, the only method of correcting the number is to retype the main or interrupt command.

### 3.4 Valid Commands

In the following, upper case letters are literal, lower case variable.

#### Waiting Loop Commands

| | |
|---|---|
| /IN<br>(Initialise) | Initialise all constants for the particular station. This will initialise regions, markers, displays and printout. This command should be used only in an attempt to restore an obvious malfunction or to initialise the station on computer switch-on. |
| /CP<br>(Cancel Program) | Cancel the current program and return to the waiting loop. This instruction will stop display and data taking as well. |

#### Region Commands

| | |
|---|---|
| /RD a: b:<br>(Region Definition) | This command defines the number of regions, a and the size of the region, b. These two numbers will be accepted subject to the following restrictions:<br>(i) a must not exceed 8.<br>(ii) b should be a power of 2; if not the next largest power of 2 will be taken. Minimum b is 32.<br>(iii) a x b must not exceed the memory allocated to the station. |

Upon acceptance of a and b all data taking, printout and display for the station will be terminated and the adjusted a and b printed out.

| | |
|---|---|
| /RZ a:<br>(Region Zero) | This command clears the contents of the region a. |
| /RC a:<br>(Region Complement) | The individual contents of region a are complemented, i.e. the contents of each channel are subtracted from 262144 and the result (modulo 262144) replaces the channel contents. |
| /RM a: b:<br>(Region Move) | The contents of region a are moved to and replace the contents of the region b. The original contents of region b are lost whereas the contents of region a remain unchanged. |
| /RS a: b: c:<br>(Region Subtract) | This command subtracts the individual contents of region b from the individual contents of region a and leaves the result in region c. Regions a and b will remain unchanged unless also specified as region c. |
| /RR a:<br>(Region Read) | Read back a region from tape into region a. The tape should have been previously punched out using the WR command. The region may be entered from the keyboard if the write format is followed precisely. |
| /RL a: b:<br>(Region Log) | The contents of region a are converted to approximately logarithmic form and the result placed in region b. Region a will remain unchanged unless also specified as region b. |
| /RA a: b:<br>(Region Antilog) | The contents of region a are converted from log to linear form and replace the contents of region b. Region a will remain unchanged unless a = b. |

Experiment (ADC) Commands

| | |
|---|---|
| /XN a:<br>(Experiment On) | Commence data taking into region a. The ADC converter range will be set to the region size by the controlling program. |

| | |
|---|---|
| /XF (Experiment Off) | Stop data taking. |
| /XT a: b: (Experiment Timed) | Take data into region a for b/10 seconds. The time taken will be a live-time measurement which may differ considerably from real-time. |

Integrate Commands

| | |
|---|---|
| /IR a: (Integrate Region) | The individual contents of region a are summed and printed out. The double precision number x + y is the number of channel overflows x and the residue y. To calculate the exact number use the relation: $\text{Total} = 262144 * x + y$ |
| /IS a: b: c: (Integrate Sector) | The individual contents of region a between channels b and c inclusive, are summed and printed. |
| /IM (Integrate Markers) | The individual contents between and including the markers of the current display or the last displayed region are summed and printed. |

Display Commands

| | |
|---|---|
| /DN a: (Display On) | Display region a. This command resets any expanded mode (see /DE). |
| /DF (Display Off) | Stop displaying data. |
| /DE (Display Expand) | The display is expanded to display all points between the markers. The actual expansion will be a power of 2 with a minimum of 32. |
| /DR (Display Restore) | Restore the display to the unexpanded state. |
| /DY a: (Display Y-scale) | Set full scale (Y-axis) to $2^a$. Note that $8 < a < 18$. |
| /DO a: b: (Display Overlay) | Overlay all regions on the display from region a to b inclusive. The display will be restored to its unexpanded state. |
| /DS a: b: c: | Display region a, set marker 1 to b, set |

| | |
|---|---|
| (Display Sector) | marker 2 to c and expand if necessary. |
| /2X (Double X-axis) | The X-axis will be contracted to double the number of channels currently displayed. |
| /X2 (Halve X-axis) | The X-axis will be expanded to display half the current number of displayed channels. |
| /2Y (Double Y-axis) | The Y-axis will be contracted so that double the current contents range is displayed. |
| /Y2 (Halve Y-axis) | The Y-axis will be expanded so that half the current contents range is displayed. |

<u>Marker Commands</u>

| | |
|---|---|
| /MS a: b: (Marker Set) | Set marker a to the b-th channel. |
| /MI a: b: (Marker Increment) | Change marker a by b channels. |
| /MW (Marker Write) | Print current marker values. |

<u>Write Commands</u> (Punch if teletype is on)

| | |
|---|---|
| /PK (Pack) | Print all integers with leading zeros deleted. |
| /UP (Unpack) | Print all integers with leading zeros replaced by spaces. |
| /WL (Write Leader) | Print approximately 13 inches of leader trailer code. |
| /WH (Write Heading) | Print the incoming characters onto the teleprinter for spectrum identification, etc. (A slash will not be printed as it is treated as the next command identifier.) |
| /WR a: (Write Region) | Print the contents of region a in either packed or unpacked format. |
| /WS a: b: c: (Write Sector) | Print the contents of region a between channels b and c inclusive, the selected format. |
| /SW (Status Write) | The number of regions, region size, display size and the current marker values are printed out. |

### 3.5 Command Nesting

As stated previously, various commands can be executed at the same time. Whether two commands can be executed together depends upon device use and whether the task is operated as a background or a foreground operation. Nesting of commands has been arranged specifically so that data taking, displaying and writing can be performed by all stations together. However, there are several sets of commands that are mutually exclusive and one cannot be called during the operation of the other without stopping or modifying the existing procedure. Commands have been classed in sets below.

Interrupt commands

These commands are used to set flags, etc. to commence or stop certain procedures. They do not require data input, as all pointers, etc. must have previously been set either by command or default. The existing interrupt commands are /XF (Experiment Off), /IM (Integrate between Markers), /MW (Marker Write), /SW (Status Write), /DE (Display Expand), /DF (Display Off), /DR (Display Restore), /PD (Plot Current Display), /PZ (Plotter Zero), /PF (Plotter Fullscale), /2X (Double X Axis), /2Y (Double Y Axis), /X2 (Halve X Axis) and /Y2 (Halve Y Axis). These commands will be executed when entered correctly via the station keyboard.

Immediate commands

These commands are used to call sequences that have to be more closely defined than interrupt commands, e.g. a region or starting address must be specified. These are /RS (Region Subtract), /RM (Region Move), /XN (Experiment On), /IR (Integrate Region), /IS (Integrate Sector), /DN (Display On), /DY (Display Y-scale), /DS (Display Sector), /DO (Display Overlay), /MS (Market Set), /MI (Marker Increment), /RZ (Region Zero), /RC (Region Complement), /RL (Region Log) and /RA (Region Antilog). These commands will be executed when correct data are received from the station keyboard. If incorrect data are received, the ERROR message will be printed at the station. Immediate commands cannot have interrupt commands inserted where data entry is required without terminating the command.

Main commands group 1

These instuctions require data input for command definition but do not require data input during the procedure execution. These commands are /XT (Experiment Timed), /WR (Write Region) and /WS (Write Sector). The command execution proceeds when correct data definitions have been received. Once in progress, Interrupt and Intermediate commands can be nested within the procedure.

Main commands group 2

These instructions require data input for command execution as well as region definition. These commands are /RR (Region Read) and /WH (Write Heading). Once the procedure has been correctly entered, the only commands that may be nested within the procedure are the Interrupt commands.

Main commands group 3

These commands are effectively those which terminate current programs. These commands are /WL (Write Leader), /CP (Cancel Program), /RD (Region Definition), /IN (Initialise), /RB (Read Binary) and /PB (Punch Binary). All these procedures upon successful entry bring control back to the waiting loop after performing their appropriate task.

## 4. START-UP PROCEDURES

### 4.1 Program Loading

The program tape supplied is coded in standard PDP9L binary loader format. When this tape has to be loaded upon start-up or after another system tape has been in operation, the PDP9L RIM format binary loader should first be loaded and this loader used to load the PHA 1 system tape into core.

The following steps should be followed:

1. Set the Address Switch Register to 17700 octal.
2. Place the binary loader tape in the reader (Console Teleprinter)
3. Depress IO Reset.
4. Depress RIM.

The tape should now read into the computer and halt at the last character.

5. Place the system tape in the reader (Station 2).
6. Depress IO Reset.
7. Depress Start.

The system tape should now load into the computer. When the tape has finished loading, the system will automatically be started, which will be indicated by each station printing a carriage return linefeed followed by /IN, etc.(see Section 7.2).

If the above loading is unsuccessful, then repeat from step 1 and if it is again unsuccessful, refer to the officer-in-charge. If the system has been stopped by depressing Stop, it may be restarted by setting the Address Switch Register to 01000 octal, depressing IO Reset and then depressing Start. If this is unsuccessful, reload the program from 1 above.

4.2 Station Initialisation

On computer start-up, each station is automatically initialised, which consists of the following operations:

(a) The teleprinter buffer is initialised.

(b) Data taking is cancelled.

(c) Display is cancelled.

(d) Regions are set up according to the default option which is normally one region made up from the maximum number of channels available to the station.

(e) The lower marker is cleared, and the upper marker is set to Region Size -1.

(f) The display is restored.

(g) /IN is printed at the teleprinter followed by the number of regions (normally 1) and the region size.

(h) Control is passed to the waiting loop.

The station is now ready to accept operator commands. If a multiple region station is required the /RD (Region Definition) command should be entered, followed by the number of regions (maximum 8), followed by the region size. The station will print the accepted definition after adjusting the region size to 2**N (minimum 32). If overflow occurs or incorrect data are received, then ERROR will be printed. If the data definition is acceptable, steps (b), (c), (e), (f) and (h) above are executed.

A station may also be re-initialised by the /IN command. This command should only be used when station operation appears chaotic as all data settings, etc. are lost.

## 5. THE COMPUTER

The computer used as the basis of the system is a PDP9L. This unit is a single address, fixed word length (18-bits), parallel binary computer. The memory cycle time is 1.5 μs and the keyboard-teleprinter sets operate at 10 characters per second. It was originally supplied with 4096 words of core memory storage and two keyboard-teleprinter units. Since then, a further 4096 words of core memory and keyboard-teleprinter set have been added; these additions were supplied by the manufacturer.

### 5.1 Features of the Basic Computer

The basic computer as supplied by the manufacturer has many features associated with its operation and input-output inapplicable to use in its present configuration. These are completely described in the manufacturer's literature and should be referred to where required. However, a brief description of those features used by the pulse height analysis system follows:

Program Interrupt This feature which is available on all small digital processors on the market, effectively frees the main program from the need to monitor the status of peripheral devices. When a device signals a request for service, the current status of the computer is stored and an interrupt service routine entered. When the service routine has been executed, the computer is restored to its pre-interrupt condition.

Data Channel This feature allows fast non-overlapping data transmission between a device and core memory. These transfers do not disturb the current program state of the processor except that program operation is suspended until the particular request has been completed. Data channel transfers normally transmit data into or out of the core memory via the memory buffer and require three or four memory cycles per data transfer.

Data Channel Increment Memory In this mode of operation the content of an externally addressed memory location is incremented by one, by using the first cycle of the normal data channel transfer. Increment Memory is a particularly useful feature when histograms or spectra are being collected from an ADC converter or similar device.

### 5.2 Processor Modifications

The basic computer has been modified to perform various functions which improve the operation of the overall system. These include the addition of an index register, the incorporation of a single cycle data transfer, addition of a positive bus and modification of the keyboard-reader interface.

Index Register This feature, which allows a memory reference instruction to vary the instruction address according to the value contained in the index register, is extremely useful when two user data areas have to be referenced by the same program. The operation of indexed instructions is basically identical to the indexed instructions used on the PDP15 (which has now superseded the PDP9L) except that limit registers are not being used.

Positive Bus The PDP9L uses a negative bus structure which is incompatible with the more recent transistor-transistor logic integrated circuits used for most of the system interfaces. It was considered preferable to convert the existing bus rather than design the equipment using discrete component techniques.

Single Cycle Data Transfer The increment memory data channel operation has been modified so that when appropriately gated, the actual memory increment is inhibited; the memory buffer has been buffered using line drivers to provide an output distribution bus for the addressed data. These modifications effectively enable the data channel to be used as a single cycle output data transfer. This particular feature has been implemented to reduce the time taken by the station displays.

Keyboard-Reader Modification The extra keyboard-reader interfaces have been modified to allow the units to operate under interrupt without advancing tape.

## 6. DATA-TAKING PROCEDURES

### 6.1 Requirement

The system was originally designed to cater for the use of multiple spectra of maximum size (1024 channels) with possible expansion to larger region sizes when the computer core was expanded. The basic requirement for the data-taking procedures of the system was that they were at least capable of duplicating the facilities of standard 1024-channel multichannel analysers. These units, which are capable of quite flexible operating modes using, for example, subgroup selection switches, can, with selectable conversion gains, take data into halves, quarters, etc. of the available channels. The data-taking procedures permit very flexible subgroup selection but selectable conversion gains are limited to those of the ADC used.

One of the more important requirements with data-taking is a low dead-time. This time is a function of both the ADC and the memory used, the larger part being associated with the ADC. Most hard-wired systems allow for this dead-time and can count in a preset live-time mode whereby a statistical correction is made for the period that the converter and memory will not accept another input pulse.

When an experiment has been performed a more accurate result is obtained if some means of background subtraction is available which deletes unwanted background interference from the main spectrum. This is usually accomplished by counting in subtract mode for a representative time with the source to be measured removed, the exact criterion being a function of stability, experiment type, etc.

6.2 General

The actual capabilities of the overall system tend to have been modified from the basic concepts because of the improvements in resolution of the more recent lithium-drifted radiation detectors. Due to the extremely small half-widths of energy peaks, a total or part spectrum needs to be expanded as much as possible. The two basic methods of achieving this goal are to increase the number of channels available to store the spectrum, or to step the zero of the converter digitally and thus use a digital window to accumulate the selected portion of the total spectrum. When these techniques are used, the drifts in the analog sections of the experiment need to be compensated to ensure repeatable results and various methods of spectrum stabilisation may be used. When a computer is used as the experimental control unit, this stabilisation can be carried out as an integral part of data taking.

The system has thus been expanded to allow for the above requirement for larger spectrum expansion by increasing the computer core size so that spectra up to 4096 channels can be accumulated. When converters capable of better than 1 in 4096 resolution are used, the converter must have digital zero shifting available. Station One currently uses a commercial ADC (ND1100 series) which is capable of 1024 channels range with Station Two using a 4096-channel converter (ND2200 series). The ADC interface has been designed to accommodate any ADC from 6-bit to 12-bit with the size of spectrum being selected by the computer *via* a teletype command. This does not over-ride the actual conversion range selected by the operator by means of the front panel switches but only defines the channel range acceptable to the computer.

6.3 Data Accumulation

The 1024-channel ADCs used are of the ramp variety with a clock rate of 4 MHz which gives an average dead-time of about 130 µs for an even spectrum. With the faster larger converters of the ramp variety which use 50 MHz to 200 MHz clock rates, the dead-times can be of the order of tens of microseconds. In the future it is envisaged that successive approximation converters would be used which have dead-times lower than 10 µs. The computer ADC input interface has been made as flexible as possible but with the restriction that inherent dead-times should be as low as possible to allow for faster converters when the need arises.

On computers with priority interrupt ADC can be serviced within 33 µs under program control. This figure for three stations is about 100 µs total if the three converters complete a conversion simultaneously or within a few tens of microseconds of each other. This results in a dead-time of about 100 µs for the worst case and 33 µs for the best. It is quite obvious that if the input frequencies are much above 1 kHz then the average dead-time will rise very significantly unless a more direct access path is used.

Due to the large delays encountered for programmed responses the system collects data from the ADC using the data break or cycle stealing mode. At present, most small computers have a direct memory increment mode, a facility which is particularly suited to pulse height analysis and histogram construction. This mode enables the contents of the memory at a particular hardware specified address to be read from memory, incremented by one and deposited back into memory, all within one computer cycle. This feature enables input devices such as ADC to be serviced during one computer cycle after the current instruction has been executed. This gives an average access time due to the computer of about 2½ cycles or about 5 µs for the PDP9L. It is worth noting that if ADC requests are piling up from separate stations, then this access time drops as the direct memory access remains engaged.

Using the /XN (Experiment On) instruction, which requires the region number to be entered when the command is accepted, enables data accumulation. The region size used for the accumulation will be the current region size as defined by the previous /RD command. All addresses from the ADC that fall outside this range are discarded. Data taking is stopped using a /XF (Experiment Off) command.

### 6.4 Live-time Counting

For more accurate counting techniques for standardisation, etc. the experiment must be run for a determined live-time to enable comparison between results. Live-time is effectively that period during which the ADC is capable of accepting an input pulse. This period is difficult to measure exactly but can be estimated reasonably correctly if input pulses are random. For this case a constant frequency clock is gated by the ADC BUSY signal; those clock pulses which occur during the non-busy conditions are scaled in a preset-time scaler. This method of live-time determination relies upon the statistical variation of the incoming signal and may become grossly inaccurate if any fixed repetition rates are present.

The live-time mode of counting is controlled from a 1000 Hz tuning fork oscillator gated by ADC BUSY and scaled under program interrupt into a preset time location. This mode is enabled by /XT (Experiment Timed) which requires two sets of data, the region number for accumulation and the preset live-time in seconds. Counting is terminated by the preset time expiring or an appropriate command.

A percentage live-time meter is provided at each station to give the operator an estimate of the difference between actual and experiment time.

### 6.5 Background Subtraction and Manipulation

The system has been designed to take data and increment a location under hardware control, but normal background subtraction in the count state is not feasible because of its inability to decrement the location as would be required to count off background.

To overcome this problem, /RS (Region Subtract) is used under which one region may be subtracted from another and the result stored in any available region. When the number of regions available is two, the experiment may be counted in one and the background counted in the other with the final result being obtained by subtraction using either region as the final destination for the corrected spectrum.

However, when all the channels available to a station are used for the largest region possible, then the above procedure is of no use. This problem is corrected by using the /RC (Region Complement) command and counting the background positively but in the opposite sense to the actual spectrum.

If the large number of regions is used then particular regions can be conveniently used for data taking and others for control spectra, etc. This facility, which is on most hard-wired systems purely for operator convenience, is available using the /RM (Region Move) procedure to transfer data between regions. A region swap instruction has not been implemented at present. This instruction would change region data without losing either of the data spectra.

## 7. DISPLAY PROCEDURES

### 7.1 Requirement

The display and its operating procedures were expected to give a performance equivalent to or better than those found with commercial pulse height analysis systems. Many of these systems use a very basic cathode ray tube with a long persistence phosphor and a minimum of X and Y adjustment. The inflexibility of the X and Y amplifiers is compensated for by having a reasonable selection of the ranges employed by the analyser. This method has been used to provide a basis for the displays used by this system except that the phosphor used was normal persistence selected basically because of operator preference.

The basis display functions required to conform with usual practice are:

- Basic spectrum display where points in a chosen data area are displayed.
- X axis range selection where the size of the group displayed can be varied and the display selected from the groups so created within the basic spectrum. These groups are generally a power of two in size and commence on a multiple of the group size.
- Y axis scaling where the effective range of the Y axis can be selected; these ranges cause Y axis overlap of the spectrum in some cases. The inclusion of log conversion hardware is available on many systems.
- Channel identification where selected channels are intensified to enable quicker reference when determing half maximum widths, peak positions, etc.
- Spectrum overlay where two or more spectra can be displayed alternately to enable comparison of particular areas, peaks, etc.

- Plotting of the spectrum using some suitable XY plotting system.

These capabilities were used as a guide to the basic functions required; most of them have been implemented with further refinements. The availability of log displays has been deleted because of the complexity of an automatic hardware log interface and will be developed only if operator inconvenience becomes excessive.

## 7.2 Facilities

### 7.2.1 Display markers

The X axis of the display is controlled using two markers; 1 for lower, 2 for upper; each of which is displayed as a vertical line on the display screen with the appropriate X axis displacement. These markers are used as a means of channel identification or as a subgroup when expansion of the display around the markers is requested. The markers have a limited significance outside the display procedures. They have no function during plotting except to define the X axis range and displacement.

Each marker may be set, incremented or decremented independently of the other. These changes will not affect the current display cycle but will alter all future display cycles. If the display is in expand mode these alterations can be extensive. Changing a marker has no effect on a plot display cycle as the cycle is still current.

### 7.2.2 Channel identification

As stated above, a particular anomaly can be located by lining up either the upper or lower marker on the anomaly using increment and set marker procedures and printing the final marker values out.

A more basic means of channel identification is provided which produces a relative brightening of every 16th point of the spectrum. The anomaly channel can be estimated quite quickly using these 16-channel boundaries. The intensified channel always has an address which is a multiple of sixteen and does not depend upon the origin of the displayed spectrum or sector thereof.

### 7.2.3 Display expansion

The X axis of the basic display can be expanded to provide more detail and more easily identifiable points. This expansion of sectors of the spectrum is defined in terms of the markers and particular instructions, under the following conditions:

- The display must be operating in the expand mode, i.e. either /DE (Display Expand) or /DS (Display Sector) must have previously been commanded and not since been cancelled.
- The display is expanded so as to include both the lower and the upper marker in its range with the actual markers being placed as centrally as practicable.
- The expanded display size is always a power of two with a minimum value of thirty-two.

When the display is in expand mode any change of either the upper or the lower marker usually results in shifting the sector origin and also causes a change in sector size if a power of two boundary is crossed. The dual intensification of every sixteenth channel is completely unaffected by the expand mode.

The display is restored to equal the region size if /DR (Display Restore) is entered at the keyboard. If the lower and upper markers are apart by more than half the region size, an apparently restored display results, but in this case the expand mode has not been cancelled.

7.2.4 Display scaling

The Y axis range of the display can be varied as well as the X axis range but in a less flexible manner. The Y axis range is again selectable in powers of two to give a full scale vertical axis between $2^{10}$ and $2^{18}$.

The vertical range is changed by shifting the 18-bit data word to align the digital-to-analog converter (DAC) with the selected 10 bits to be used for the Y axis deflection. All other bits are ignored resulting in vertical overlap of the spectrum bands. This feature is usually of little significance as the range is selected mostly to show a particular sector or group without vertical overlay occurring. As the stored spectrum increases the display can be varied to suit.

7.2.5 Display overlay

When the station data region has been divided into smaller working regions it is possible to overlay these on the display screen. This technique is normally used for comparison of peak positions and intensities. Any number of regions may be overlayed from the station keyboard with the following restrictions:

- The overlay must be compatible with the number of regions specified by the previous /RD (Region Definition).

- The regions to be overlayed must be consecutive as the starting addresses are generated using the display region size as the basic increment.
- If called, the plot routine does not plot more than one display which is the first region to be displayed. For convenience, /PD (Plot Current Display) should not be used while the overlay mode is active as the resulting plot will obviously differ from the display.

## 7.3 Display Quality

The method of display is controlled by the display oscilloscope used and by the quality of display required. Ideally the display should be flicker-free but this need not be realised. The display obtained with the existing display oscilloscope has noticeable flicker at 100 µs per data point for a 1000-channel display. This flicker is reduced sufficiently if the time per data point is reduced to 70 µs; if a time of 50 µs is allowed for, there is sufficient time available for the display of markers, etc. without introducing excessive flickering.

### 7.3.1 Persistence

Two necessary methods of improving the display were investigated, one using long persistence phosphor display tubes and the other interleaving the display for larger spectra. The long persistence tubes displayed initially with a blue glow followed by a yellow afterglow which was still detectable ~ 0.1 s after the initial intensification. The performance of this tube was compared with a cheaper tube having a green glow and afterglow which persisted for a noticeably shorter time. However when the two tubes were compared the qualities of the two displays were still comparable but the longer persistence blue glow yellow afterglow was harder to observe without eye strain. Because of the objection to this by the intended operators, the normal persistence tube was used. A storage tube was considered to be outside the required budget and is subject to particular limitations regarding clearing the previous display.

### 7.3.2 Interleaving

Improving quality by interleaving resulted in a significant improvement of the display especially for larger spectra. The data to be displayed can be set up and displayed quite simply under software control in about 33 µs per point using an interleaving technique which steps the address (or X axis) in steps of 2**N (in this case 16). The resultant flicker is noticeably less than for sequential channel display as most of it is spread out by the interleaving. The best method for interleaving was determined experimentally by comparing the display produced for a series of ramp displays. Interleaving four spectra, each separated by one channel, gave a reasonable display at 200 μs per point. Any increase to 8 or 16 interleaved spectra produced a definite cycling nature in the overall spectrum which in some cases was worse than the non-interleaved spectrum.

7.3.3. Hardware controlled display

Using the interleaved software display above, the display rate can be dropped quite significantly without reducing the quality of the display too much. This enables three stations to display simultaneously with the following restriction: each display is scanned on a station basis which introduces flickering because of the dead period while other stations are displaying. This can be reduced but only if the displays are station interleaved, increasing the size of program required and also reducing the overall display rate.

The alternative method of displaying the data is to use the data break or cycle-stealing facility available on the computer. Using this, the address of the data to be displayed is presented to the computer with a break request and the contents of the address are loaded into a buffer when the request is granted. The resultant X and Y values then have to be modified and shifted into the specified ranges before the point is ready for display. The data break request can be controlled by a 20 kHz oscillator to give the required 50 μs display per point.

The hardware mode of display using data break takes one cycle per point for the actual display and has little effect on the program in operation except for the loss of this cycle; many stations can be displayed simultaneously with no reduction in display quality. The display cycles for each station are interleaved and the resultant display for one station operating is the same as for many. Each display sweep requires certain data to effect the hardware operation. This setting up is quite short, only occurring at 5-100 ms intervals at most.

7.3.4 System used

The method of displaying data consists of a non-interleaved display sweep under hardware control at approximately 50 μs per display point per station. While a spectrum of 4096 points can be displayed with detectable but not excessive flickering, the more usual display of 1024 points or less is excellent. For overlayed displays of 1024 points they are noticeably cyclic.

When this system is used by three stations simultaneously, approximately 10% of machine time is used. This is not excessive but requires exact allocation of hardware priorities when used with fast ADCs which are affected by increased dead-times. The display can be further improved using interleaving but this requires a lot of hardware which is probably not justified.

7.4 Display Operation

The display procedures have four different modes of operation to cover all foreseen requirements. These modes are selectable when status bits are loaded into the display control register. However, the tasks associated with these modes are split into three groups, those performed under mainline program, under interrupt controls, and by direct memory access. The four basic modes and their requirements are:

- Marker Display (MARK) is used to write a vertical row of points on the display scope. It requires a fixed X axis, the Y axis being incremented in fixed steps with no particular accuracy required.
- Zero Display (ZERO) is used to adjust an XY plotter such that the zero and fullscale points correspond to the plotting bounds required. For this case, the X and Y axes are either fixed at zero or at fullscale. This mode does not generate an intensify signal to prevent burning spots on the screen.
- Plot (PLOT) is simply a slowed display mode where the channel advance signal is generated from a plotter-finished signal instead of from a clock train. The plot mode is reset after one sweep of the required segment.
- Display (DISP) is used to display the current requirement on the display oscilloscope. Each data point is generated from the X axis and data from the corresponding region location. These contents are shifted to allow for scaling of the final spectrum. Each point is intensified with each sixteenth point being intensified twice to aid channel identification.

These modes are initiated in various phases, some being completely specified under mainline control while others rely on initiation only during mainline and use the interrupt and direct memory access facilities for their actual operation. Each mode is basically different and is described separately in conjunction with the relevant command procedures.

7.4.1 Plotter control

The plotter runs in close conjunction with the cathode ray tube display and uses the same ADC and data retrieval circuitry. The simplest of the plot commands use the ZERO mode and are completely specified under mainline. These are /PF (Plotter Fullscale) and /PZ (Plotter Zero) which simply load the X and Y axis data registers with all ones or all zeros respectively. The remaining plotter command /PD (Plot Display), which uses the PLOT mode command, is initiated under mainline and executed using direct memory access. The plotter is operated asynchronously using the plotter echo signal. All counters, masks, etc. must have already been specified by the preceding display sequence.

7.4.2 Display control

The display is controlled in three separate phases, the mainline phase which is entered and updated whenever a relevant command is received, the interrupt phase which is updated at the completion of every hardware task, and the direct memory access phase which is controlled by the interface display clock. The only operating modes used are DISP and MARK.

The overall display consists of the data spectrum followed by the lower then the upper marker followed again by the data spectrum. If display overlay is used, the markers are displayed between each separate data spectrum. Both the DISP and MARK cycles generate an interrupt when complete, which enters a monitor program to load the two display status registers with composite words generated from the scaling factors, initial addresses, etc. required for the next display phase.

The display can be activated by either /DR (Display Region), /DS (Display Sector) or /DO (Display Overlay) commands and is stopped by /IN (Initialise), /RD (Region Define) or /DF (Display Off). Once commenced, the display cycles continuously as a background computer task, requiring only the single cycle of computer time stolen for each data word at approximately 50 μs intervals and setting up time of the next phase. The MARK mode does not require processor time until complete when the next mode must be set up.

### 7.5 Logarithmic Display

For most spectra, a more precise display can be achieved using a logarithmic scale which enables a better appreciation of the relationships of all peaks to their associated troughs regardless of their value. On a linear scale, these relationships tend to be lost because smaller peaks are lost on the base line. If incorporated in digital hardware, the log display requires extensive gating, etc. If incorporated in the analog circuitry it requires a logarithmic amplifier which generally has a very slow response time.

A simple approximation to log can be achieved by generating a 4-bit exponent with a 14-bit linear mantissa of which 6-bits only are actually displayed. When data have been converted to logarithmic form, data-taking should not be operating and the data should be reconverted to linear before /XN or /XT is initiated.

Because of the 4-bit exponent the maximum recoverable precision of re-linearised data is 15 bits, i.e. 14 data bits (mantissa) and 1 exponent bit. On the reconversion, the first bit that was truncated is set to one which results in a maximum error of 4 for data > 130 K, 2 for data > 64 K and 1 for data > 32 K. This error is well within statistical tolerances. The appropriate instructions are /RL (Region Log) and /RA (Region Antilog) both of which are set up as a move instruction in case a spare region is available.

## 8. DATA RETRIEVAL PROCEDURES

Data contained in the computer at some stage are generally required to be stored, either as hard copy from a printer or on perforated paper tape, for entry into a larger computer or re-entry into the system at a later time for comparison, etc. For entry to a larger computer, magnetic tape is more convenient but for this system paper tape is much more economic for the usage expected. Data may also be required as intensity measurements when the number of separate counts in the spectrum is required.

### 8.1 Write Commands

When data are to be typed on the station teleprinter, either the /WR (Write Region) or /WS (Write Sector) command is initiated. The resulting data output consists of channel identification at the commencement of each line followed by the contents of that channel and the following seven channels. The start of the sector when /WS is used need not be at a multiple of eight and can be at any valid channel within the specified region; examples are shown in Section 3.4.

If other procedures are to be nested within the Write procedure (see Section 3.5), the following restrictions apply. All commands may be entered at the keyboard during the Write procedure and these will be acknowledged and executed at the end of a line. After their execution the Write will continue unless it has been terminated. If /IN or /CP is entered, the command will be acknowledged at the end of the current data word and the Write will be terminated. Nesting within the Write has been used to overcome the exceedingly long down-time that results when a large spectrum is printed.

The Write tape can be considerable shortened if the packed format is used. For most spectra, suppressing the space during printout reduces the printout time by about 60% if the standard station teleprinter is used. However, the paper tape perforator associated with the station teleprinter is not independent of the type mechanism and so commands should not be entered if an unmarked copy suitable for re-entry is required.

8.2 Read Commands

This command is used to read a tape in Write format back into a region for comparison purposes or for further processing. An operator may enter data into a region using /RR (Region Read) and using the keyboard as the data entry point. However, the format (excluding spaces, carriage returns and rub-outs) must be entered exactly as for standard format including correct channel identification otherwise the procedure will abort.

8.3 Punch Binary and Read Binary

Data output from the computer on paper tape that is to be used as input to the site computer preferably needs to be as short as possible and not necessarily in readable character format. An 18-bit word can be punched in binary as three 6-bit paper tape characters in a similar format to the computer load tapes. By using the spare 2 bits for parity and control, leading zeros can be deleted so that up to 12-bit data require only 2 characters and up to 6-bit data require only 1. This format, developed by Dr. J.A. Biggerstaff, has been followed to enable the use of library routines on the AAEC IBM360/50 computer.

The binary tapes can be read back using /RB (Read Binary). The tapes, which are punched in odd parity cannot contain a slash character so that the procedure can be aborted by typing any command. The punch procedure allows for a run number to be punched at the start of the tape. The procedure is called by /PB (Punch Binary). Note that each of the three stations shares the fast paper tape perforator so that only one station can access the procedure at one time. The binary tapes must be read back on the station teleprinter.

### 8.4 Integration

If effective intensities, etc., of peaks have to be compared or tabulated, then the integration commands are used. These commands integrate the spectrum or sector thereof and output the result on the teleprinter without affecting any data.

Three commands are available, /IR (Integrate Region) which requires the region number as data, /IS (Integrate Sector) which requires the region number, lower inclusive bound and upper inclusive bound as data, and /IM (Integrate Markers) which integrates between the markers of the current display. The last of these commands is basically for peak intensity measurement whereby the markers are visually positioned to straddle the peak at the desired bounds before initiating the /IM command.

## 9. INPUT-OUTPUT PROCEDURES

### 9.1 Function

The input-output procedures govern all data transfer between the user and the computer via the keyboard, keyboard reader and teleprinter. Input to the computer consists of data to the integer input routine, characters for the /WH (Write Heading) instruction and actual commands to request separate instruction procedures. Output from the computer consists of acknowledgement of instructions and printing of separate results and heading characters on the teleprinter.

### 9.2 Keyboard and Keyboard Reader Operation

The keyboard and the keyboard reader of the ASR33 Send-Receive teleprinter which is used for computer communication, both use the same input channel, the only difference being that the keyboard reader requires an instruction to advance the tape through the reader.

When a character is expected on either the keyboard or keyboard reader, the Input Character subroutine (IPCH) is called. The subroutine executes a fetch character instruction and sets a software flag (SINPX) negative, indicating that a character is expected. When the character is received, the flag is set to the code of the input character (always positive) and the return is via the saved subroutine entry.

When characters are expected by the command sequence (initiated by typing a slash) two characters are required to complete the required instruction format (/ ch ch). When a slash is input to the computer, a signal expected flag (SSIGX) is set to -20 to indicate character expected, and the fetch character instruction is executed (i.e. commands may be entered on the keyboard reader). The signal expected flag is incremented every second until it reaches zero or two characters are received. If the flag reaches zero, any command or part thereof will be aborted and a new command sequence must be commenced. If two characters are received before being counted out (i.e. within twenty seconds), they are sorted in the command table search routine (SORT).

9.3 Teleprinter operation

Teleprinter operation is controlled using a buffer of 16 characters. When a request to print a character is initiated by the output character subroutine (OPCHH), the character is loaded into the next sequential (modulo 16) location in the print buffer and the buffer character count is incremented by one. The buffer is printed out sequentially (modulo 16) by the interrupt service routine for the teleprinter until the buffer count is zero. The output character subroutine is not re-entrant so that if the print buffer is full, the subroutine will wait until room becomes available before returning to the calling routine.

9.4 Character Input-Output Routines

IPCH Input a Character routine This routine executes a keyboard reader fetch instruction and waits for the character by calling the supervisor. The resultant 8-bit character is masked to 7 low order bits, the most significant bit is set to 1 and is returned to the calling program as the content of the accumulator.

OPCHH Output a Character routine This routine prints the low order 8-bit of the accumulator as an ASCII character (see Section 9.3).

TY3 Output 3 Characters in trimmed code This routine prints the 3 characters contained in the C(AC) in 6-bit trimmed code (that is, all ASCII codes between 240 and 337 with the two most significant bits trimmed off).

CRLF Print Carriage Return Line-Feed Self explanatory.

9.5 Integer Routines

Input routine (INTIN) This routine is used whenever data are required by the station either for command specification or for actual data. This routine operates in strict conversational mode and no printout is received if illegal characters are entered, or certain characters which are legal in particular areas only. The characters accepted are:

- Carriage return (CR) This character is legal while the input number is unsigned and zero. The resulting carriage return linefeed is used for formatting input data when required.
- Minus Sign (-) This character is legal while the input number is unsigned and zero.
- Decimal Digits (0-9) These characters are legal in all cases and will always be accepted. Should the integer number overflow, there is no indication and truncation will occur.
- Rub-out This character causes all input to be cancelled and a new integer must now be entered. A space will be printed to indicate erasure.
- Colon (:) This character is used to delineate the integer input stream and causes acceptance of whatever data have been entered. A rub-out will not over-ride a colon.

The routine is capable of accepting any number between ± 262 143 without overflowing. A number will be treated as positive or negative depending upon its context, negative numbers being used only for the increment routines.

When the integer input routine is entered, the supervisor entry is saved because the input character routine calls the supervisor. This entry is restored when a number has been accepted to enable re-entry to the existing procedure.

Output Routine (IOUT) This routine is used whenever printed data is required by the station. It outputs the contents of the accumulator as an unsigned positive single precision integer (i.e. 0 to 262 143). The number will be terminated with a colon to enable compatibility of tapes with the input routine (INTIN). Leading zeros are suppressed and replaced by spaces. If the PACK indicator is set, these leading spaces will be deleted.

# 10. SOFTWARE PROCEDURES

## 10.1 General

This section describes the operation of some main functions, conventions and data allocation to aid future programmers should system modifications become necessary. Many of the routines used in the program are not mentioned at all and, when this is the case, calling sequences may be given in the program listing. Comments in this listing can also be used as a guide to the operation of particular routines.

Many of the routines will appear to be slightly more complex than necessary because most procedures have to be capable of operating with all the pulse height analysis stations when required. It is basically due to this changing of program control that these conventions are listed.

## 10.2 Requirements for each Station

Each station uses the routines which control the main tasks to be performed on or by each station. However, to accomplish this with a large degree of independence between the separate stations, there are certain functions and data areas that have to be allotted to each station to be used solely by that particular station. These requirements are:

(a) Each station must have its own data region for accumulation and storage of pulse height analysis data or spectra. This data area is defined on rigid boundaries and must be a power of two in size. The lower boundary is established by any address that is a multiple of the region size. Provided that these two conditions are satisfied, all the available core storage can be allotted. In the present system using an 8K PDP9L this available area is 3000 - 17777 octal, the normal divisions being 4000 - 7777, 10000 - 13777 and 14000 - 17777 octal giving each station 2048 decimal channels and leaving 512 decimal extra program capacity.

(b) Each station must have its own data region for storage of entry points, semi-permanent and permanent data, station software flags, input data and particular device instructions. This data region is normally referenced using an indexed instruction and is only referenced directly to set preliminary pointers upon program start and restart. This data region is approximately 44 decimal locations for each station.

(c) Each station must have its own teletype buffer for storage of sixteen output characters. This buffer must commence at a multiple of 40 octal.

(d) Each station must have its own device service routine consisting generally of the device skip followed by a call to a common service routine for that device type. The call to the common routine generally requires argument passing, in the form of an index register value pertinent to the operating station.

10.3 <u>Station Capability</u>

As stated above, each station has a defined region allotted to it. This region can be re-defined as a number of alike regions of proportionately smaller size. These operating regions can be used to perform a variety of tasks simultaneously. Any station is capable at one time of:

(a) taking data from the analog-to-digital converter into any region,

(b) displaying any region or overlaying a number of regions,

(c) printing out any region in either format but preferably Write format, and

(d) performing subsidiary functions on any region such as clearing, complementing, integrating, etc.

Some functions of the commands must be mutually exclusive, and so all commands cannot be nested within other commands and precedence of order will be dictated by the operating system.

All interleaving of command functions is not subject to any commands or functions being carried out by any other station and all stations may accumulate, display and printout without significant interaction.

10.4 <u>Passing of Control</u>

When control is passed from the current operating program to another, this procedure is executed by the supervisor routine which saves appropriate entry points, etc. (see Section 10.5). There are two main types: passing control from one station to another and passing control within a station, the former case being much more precise.

(a) Passing Control between Stations. When control is passed between two stations, there is no apparent interaction between the stations and there is no change in the procedures regardless of what tasks the other stations are performing. Transfer of control is accomplished by saving the exit point in the indexed data region and changing the setting of the index register. When control is returned to the station, this exit point is picked up and station operation proceeds. Control is passed between stations as often as possible with the restriction that suitable change points are entered, these coming from mainline routines or re-entrant subroutines. The maximum delays upon changing station control can be of the order of one second in extreme situations and during this period the teletype will accept a character but will not print it until control is restored.

(b) Passing Control within a Station. When control is passed to one operating routine from another in the same station there may be significant change in procedures. The method of passing control once the previous exit point has been saved by the supervisor is to

- Print CR, LF, /XY on the teleprinter where XY denotes the command.
- Clear the command register.
- Clear the packed flag.
- Exit to the new command routine.

At this stage the exit from the previous procedure is still saved and control can be passed back without any effect upon the old procedure except for the associated command printout. However, in the execution of various procedures there are several that are mutually exclusive and these cannot be commenced without destroying the previous procedure entry and data locations (see Section 3.5).

10.5 Supervisory Functions

The supervisor routine is used to pass control from station to station and to perform the simple housekeeping tasks associated with any change of program control. The supervisor routine is called whenever a station is waiting for some physical action to occur and, as such, no more computer time is required apart from looping to check the occurrence of a particular event or events. These looping or waiting stages are due to the computer and the device operating at vastly different speeds, particularly the keyboard input which has to wait for the operator to enter correct data, etc. The four basic waiting states are:

(a) Data are required by a command or procedure that must be entered at the teletype keyboard or the keyboard reader,

(b) An experiment is being run for a preset time before performing any other operations,

(c) The station is printing a large amount of data on the teleprinter which is well in excess of the 16-character output buffer,

(d) The station has completed all requests asked of it and is waiting for a new command to be entered at the keyboard or keyboard reader.

The supervisor has two calling sequences, these being used depending upon what changes are permissible without losing re-entry points to the main program. This problem is more concerned with passing control to different routines whilst still operating within the confines of a particular station than it is with passing control between stations. The two entries, the open and the restricted case, are used depending upon the state of the current task and the conventions required, the open case covering all sequences performed in the restricted case. The restricted supervisor keeps track of:

(a) The supervisor return which must be saved prior to transferring control.

(b) The station indicator which denotes the station in control and which must be modified before passing control to the next station.

(c) The station index register value which is derived from the station indicator and which is set to the value of station indexed data region.

(d) The station command request register but only when the required command is /IN (Initialise) or /CP (Cancel Current Program). If either of these procedures is requested, control is passed within the station and previous intra-station entry points are lost.

The open supervisor keeps track of:

(a) All functions listed above for the restricted call.

(b) All requests present in the command request register.

If any command is requested, control will pass to the appropriate routine with intra-station entries being maintained or lost depending upon the particular command.

The supervisor is called from:

(a) Input Character routine (IPCH). This open supervisor call is required to wait for the next character.

(b) Waiting Loop (WAIT) as for (a) above.

(c) Experiment Preset Time. The open call is required to wait for the experiment time out period.

(d) Leader routine (LEAD). This restricted call is required to allow transfer of control to other stations while approximately twenty seconds of leader is being punched.

(e) Write routine. This restricted call is used between writing integers when a region or sector is being printed out to allow transfer of station control.

(f) Write routine at the end of each line. This open call is used to execute commands that may be simultaneously executed with printout, e.g. display, data collection, etc.

## 11. EXPERIMENT INTERFACE

The experiment interface can be split into three separate groups, the positive bus and real time clock, the station ADC interface and the station display controller. The positive bus conversion has the capability of driving the display and ADC controllers which are duplicated for each successive station. The only other multiple controller which is required for the station teleprinters was supplied by the computer manufacturer.

### 11.1 Real Time Clock

The clock which is used for system timing and also for distribution to each station for the generation of the ADC live-time clock is generated from a 1000 Hz tuning fork with shaping stages and a power output stage. The operation of the clock has been arranged to coincide with that supplied by the computer manufacturer with the exception that the controlling input-output signal codes have been varied to avoid confusion.

The clock operates as a program interrupt device that is detected by a skip instruction. It can be enabled or disabled by instruction and will be disabled by default on computer start-up. The controlling instruction codes are:

702001 Skip if clock flag is set

702044 Clear flag - Enable clock

702004 Clear flag - Disable clock .

11.2 Analog-to-Digital Converter Interface

The ADC interface performs two basic functions, the determination of experiment live-time and incrementing the contents of the channel referenced by the ADC data word. The converters are controlled using the following signals or their complements:

(a) ADEN This signal is required by the ADC to enable conversion to proceed.

(b) ADCR This ready signal from the converter indicates that a conversion is complete and the unit is ready for data transfer.

(c) ALT This indicates overflow has occurred during conversion.

(d) CLRADC This is required to clear the data word before the next conversion can commence.

(e) ADCB This indicates that time for which the converter is unable to accept input pulses.

(f) ADDRESS This indicates the data address word from the current conversion.

These or very similar signals are available with most commercial ADCs and very simple gating and level conversion logic is required to enable control of most commercial units using the interface structure as designed.

The maximum speed of operation is controlled by the analog to digital conversion time. This maximum speed can only be achieved if the interface consists of a data buffer register into which the ADC data address word is strobed, and the ADC is immediately cleared to enable the next conversion to commence if requested. Also if an overflow is detected, the converter should be cleared immediately. This mode of operation is quite feasible for low latency timing for the data-channel memory increment. The next ADC request is inhibited until the increment cycle is complete, in case the latency time has exceeded the conversion time of a subsequent event. The dead-time of the ADC and the system is taken from the incoming event to the ADC clear signal. During this time, which is indicated by ADCB, clock pulses are inhibited from setting the ADC live-time clock which is used to count live-time in the processor under program interrupt control.

The system is required to operate on a multiple station, multiple region basis and so the ADC interface must be able to control the incoming region size and the actual starting address of the selected region. This is accomplished by using a mask register which enables the selection of particular bits from the ADC and particular bits from a starting address or base register. An input data word that falls outside the mask is detected as an overflow signal and is treated exactly as overflow signals from the ADC itself, and the converter is cleared in preparation for the next input signal. An input data word that falls within the allowable mask has a starting address added to it and a direct memory increment is requested of the processor at this composite or effective address. The mask register length is controlled by the size variation required. The mask must span up to the maximum size permissible but need not span below the minimum size permissible as these low order bits have a fixed operation. The effective starting address logically must span all computer addresses required for the operation of the particular ADC (see Figure 2).

The ADC mask is logically situated between the input data word and the address buffer and operates in the following manner:

- If the mask bit is set the effective address bit is set from the ADC output and the previous contents of the effective address are lost.
- If the mask bit is clear, the effective address bit will have been set by the original status loading. The input from the ADC is not required and is inhibited. If, however, the ADC input bit is set, an overflow has resulted and the appropriate action is taken.

The ADC control is set by loading the status word from the computer when operation is required. The formats of masks, etc. contained within this status word enable operation from a 64-channel region to a 4096-channel region in powers of 2 (see Figure 3). The mask for the ADC can be generated by decrementing the region size by unity and right shifting six places. When a particular mask bit is set, all lower order bits must also be set.

The ADC interface is controlled using three input-output transfer pulses, two associated with the live-time clock interrupt and one required for status loading. For X = station number - 1, these instructions are:

| | |
|---|---|
| 70X501 | Skip if Live-time Clock Flag is set |
| 70X502 | Load ADC Status Word |
| 70X504 | Clear Clock Flag above. |

Bit assignments are given for the status word in Figure 3; if disabling only is required then the following should be issued:

| | |
|---|---|
| 70X512 | Clear Accumulator and ADC status. |

11.3 Display Interface

The display interface is capable of operating in four different modes (see Section 7.4). These modes are MARK, ZERO, PLOT and DISP and are set from the computer using the display status words. The display control basically consists of a series of registers (see Figure 4) which can be loaded from the computer, two DACs capable of better than 1 in 2048 resolution and mode control gating. These registers form the major part of the status words loaded from the computer and are loaded with initial address, spectrum masks, etc.

The mode of operation is selected by setting the appropriate list in the X axis control register (Status Word 1). The assignments are as follows:

| | |
|---|---|
| Bit 00 | MARK |
| 01 | PLOT |
| 02 | DISP |
| 03 | ZERO |
| 04 | Display Flag |
| 05 | Spare |
| Bit 06 | X axis value or mask |
| ⋮ | X axis value or mask |
| 17 | X axis value or mask. |

The display flag is cleared by setting the next display cycle or by clearing bit 04 of the accumulator and loading status. There are three basic input-output transfer pulses used to load status and detect display interrupts. These are (for X = station number - 1):

| | |
|---|---|
| 70X601 | Skip if flag is set |
| 70X602 | Load Address Status, Clear X axis register |
| 70X604 | Load X axis Status and Mode Control. |

The functions of the two load instructions are quite different for each mode and are particular to the mode selected. Normal operation requires setting up a function and waiting for the computer to be interrupted to indicate mode complete.

(1) ZERO Mode

When ZERO is selected the Y axis DAC is set from the X address register and the X axis DAC is set from the X axis control via the X axis. Maximum or minimum settings are loaded from the computer as required (see Figure 5). The instructions used are:

| | |
|---|---|
| 20 | Load required Y value into C(AC) |
| 70X602 | Load Address Status |
| 20 | Load required X and ZERO bit |
| 70X604 | Load X axis status and commence ZERO mode. |

(2) MARK mode

When MARK is selected the X axis is jammed to the value of the X axis control which is loaded from the central processor (see Figure 5). The Y axis is derived from the six least significant bits of the Address register which is stepped at the rate of one pulse per MARK cycle (50 μs), which gives a marker consisting of sixty-four points. On completion of the marker writing, an interrupt is signalled to the computer by setting the display (Status bit 04). The appropriate commands are :

| | |
|---|---|
| 70X612 | Clear Accumulator - Clear Address |
| 20 | Get Marker Value and MARK bit |
| 70X604 | Load Marker Value and Write Marker. |

The ensuing interrupt is detected and cleared by:

| | |
|---|---|
| 70X601 | Skip if Display Flag Set |
| 70X616 | Clear Accumulator and Status. |

(3) DISP mode

The DISP mode of display control writes one data spectrum across the screen and upon completion interrupts the central processor. The X component is generated from the X axis register and the Y component is generated from the data at the appropriate address. During the DISP and also the PLOT mode, the X axis address and X axis registers operate as scalers which are incremented before each point is displayed (except channel zero). When a display cycle is being requested the following parameters must be specified:

(a) Region size which is required to enable expansion of the display to use all the available screen.

(b) Region start to specify where the data spectrum commences.

(c) Y axis scale factor which is required when shifting the 18-bit Y axis data word to align with the selected 10 bits of the DAC.

(d) Display mode must be specified.

Items (b) and (c) above are specified using the X address control word (Figure 6) and the region size is specified in the form of a control mask which operates as follows:

(a) If a mask bit is set, the X axis bit is enabled from the appropriate X control bit and can be incremented.

(b) If the mask bit is clear, the X axis bit is jammed clear and clock pulses are gated to increment the next significant X axis bit.

A display point operates as follows (except channel zero):

(a) The X address is incremented by one and a data channel output transfer is requested.

(b) The X axis is incremented in steps of 1 to 128 in powers of 2 according to the mask value.

(c) Upon completion of the data channel output transfer, the data are shifted right that number of places contained in the Y shift register.

(d) After a suitable delay, an intensify pulse is generated.

(e) After the intensify period an X increment pulse is generated.

Every sixteenth point on the X address register is detected and re-intensified without altering the X or Y settings. When the X axis overflows a flag is set to indicate completion of the cycle.

(4) PLOT mode

The PLOT mode operates exactly as for the DISP mode with the exception that the X increment pulse is generated from the Plotter Echo signal which in turn is derived by the plotter when balance and plot have been completed.

Instructions used to generate display and plot are:

| | |
|---|---|
| 20 | Get starting Address and Y shift |
| 70X602 | Load X address status, clear X axis |
| 20 | Load X axis mask and mode control |
| 70X604 | Load X axis control and commence selected mode. |

The ensuing interrupt is again selected by:

70X601 Skip if Display Flag set

70X616 Clear Accumulator and Status (Disable Display).

The completion of a PLOT sequence cannot be distinguished from the completion of a DISP or a MARK sequence.

12. CONCLUSION

This system was developed to replace one needing several multi-channel analysers, at approximately the same capital cost but with the added advantages of flexibility and adaptability. The system can duplicate most functions that are available with current hard-wired multi-analysers and if required can be software modified to perform extra tasks which become necessary for operator convenience.

The most important advantage obtained using a stored program computer over a hard-wired machine is that system modifications can be undertaken by modifying the control program with the knowledge that if the modification is incorrect, the old unmodified program tape may be reloaded. However, if wired hardware is modified, errors may be very difficult to locate and will cause considerable down-time which effectively prohibits progressive changes in most commercial hard-wire multi-channel analysers.

The most obvious disadvantage encountered with the system is the variability of dead-times, etc. due to the slight interactions between stations which although minimised cannot be completely avoided. These are easily allowed for as system dead-times are well below the ADC dead-times encountered at present and will be below those anticipated for the faster converters of several years hence.

The system as described if compared with two multi-channel analysers is uneconomical if the flexibility of the system is not allowed for. However, with the large decrease in cost of the more recent equivalent digital computers, it is feasible to consider a one-computer one-station system on an economical basis.

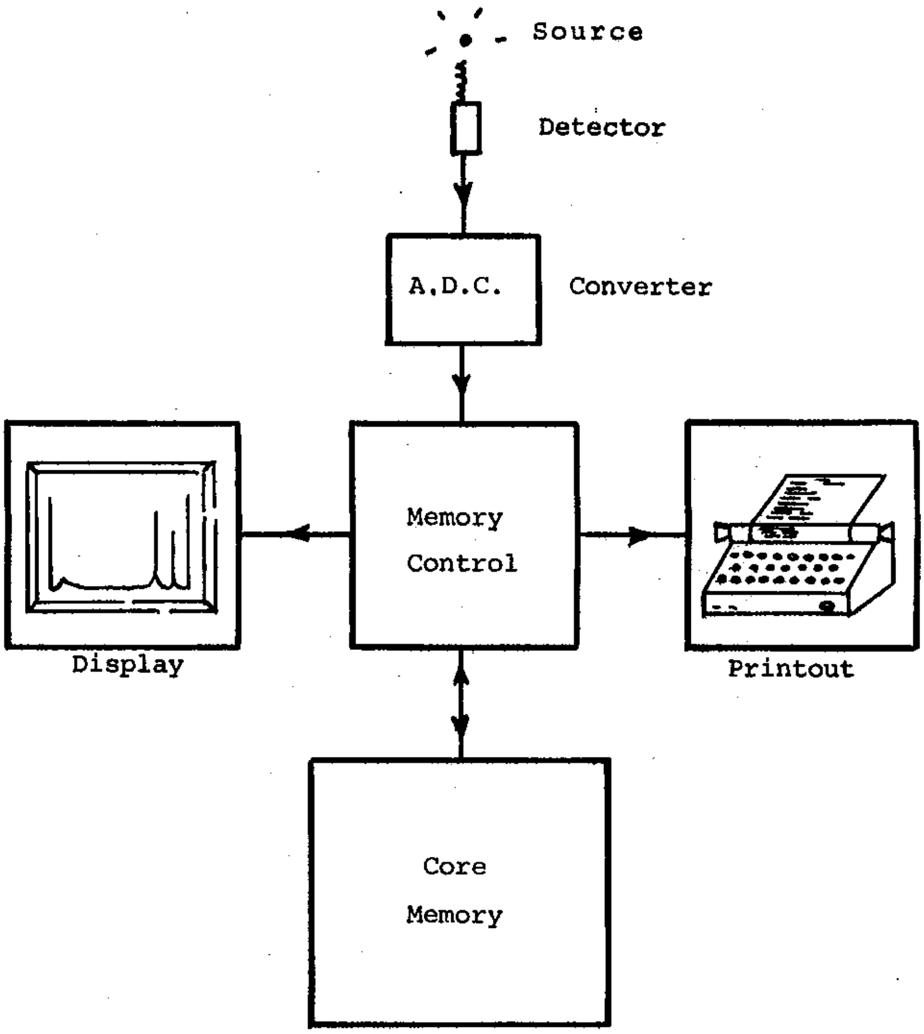


**FIGURE 1. BASIC PULSE HEIGHT ANALYSIS SYSTEM**

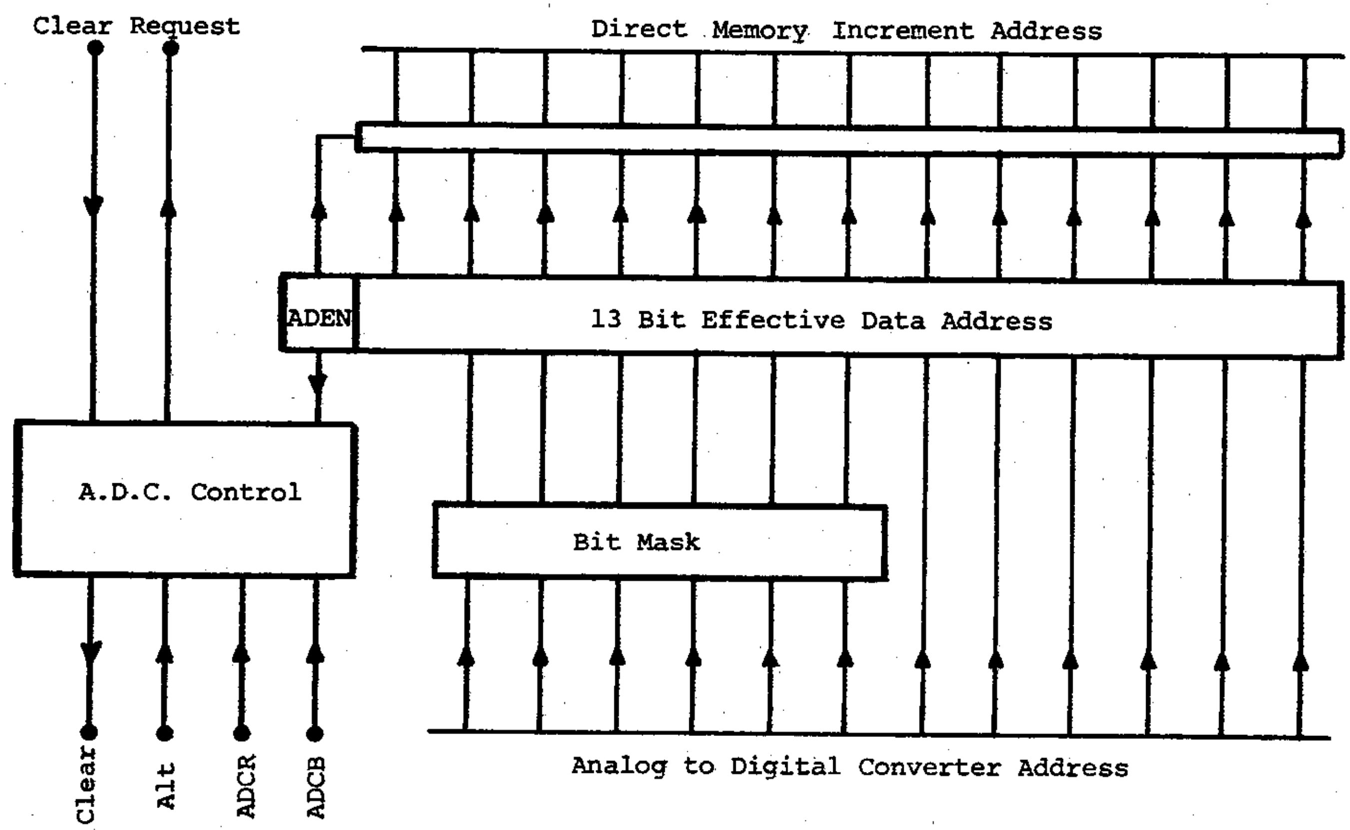


FIGURE 2. ANALOG TO DIGITAL CONVERTER CONTROL

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REGION | ADEN | NOT USED | | | | STARTING ADDRESS | | | | | | | BIT MASK | | | | | |
| 64 | 1 | | | | | S | S | S | S | S | S | S | 0 | 0 | 0 | 0 | 0 | 0 |
| 128 | 1 | | | | | S | S | S | S | S | S | Ø | 0 | 0 | 0 | 0 | 0 | 1 |
| 256 | 1 | | | | | S | S | S | S | S | Ø | Ø | 0 | 0 | 0 | 0 | 1 | 1 |
| 512 | 1 | | | | | S | S | S | S | Ø | Ø | Ø | 0 | 0 | 0 | 1 | 1 | 1 |
| 1024 | 1 | | | | | S | S | S | Ø | Ø | Ø | Ø | 0 | 0 | 1 | 1 | 1 | 1 |
| 2048 | 1 | | | | | S | S | Ø | Ø | Ø | Ø | Ø | 0 | 1 | 1 | 1 | 1 | 1 |
| 4096 | 1 | | | | | S | Ø | Ø | Ø | Ø | Ø | Ø | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | EFFECTIVE ADDRESS FOR DATA WORD | | | | | | | | | | | | |
| 64 | | | | | | S | S | S | S | S | S | S | A | A | A | A | A | A |
| 128 | | | | | | S | S | S | S | S | S | A | A | A | A | A | A | A |
| 256 | | | | | | S | S | S | S | S | A | A | A | A | A | A | A | A |
| 512 | | | | | | S | S | S | S | A | A | A | A | A | A | A | A | A |
| 1024 | | | | | | S | S | S | A | A | A | A | A | A | A | A | A | A |
| 2048 | | | | | | S | S | A | A | A | A | A | A | A | A | A | A | A |
| 4096 | | | | | | S | A | A | A | A | A | A | A | A | A | A | A | A |

**FIGURE 3. ADC CONTROL AND ADDRESS BIT ASSIGNMENTS**

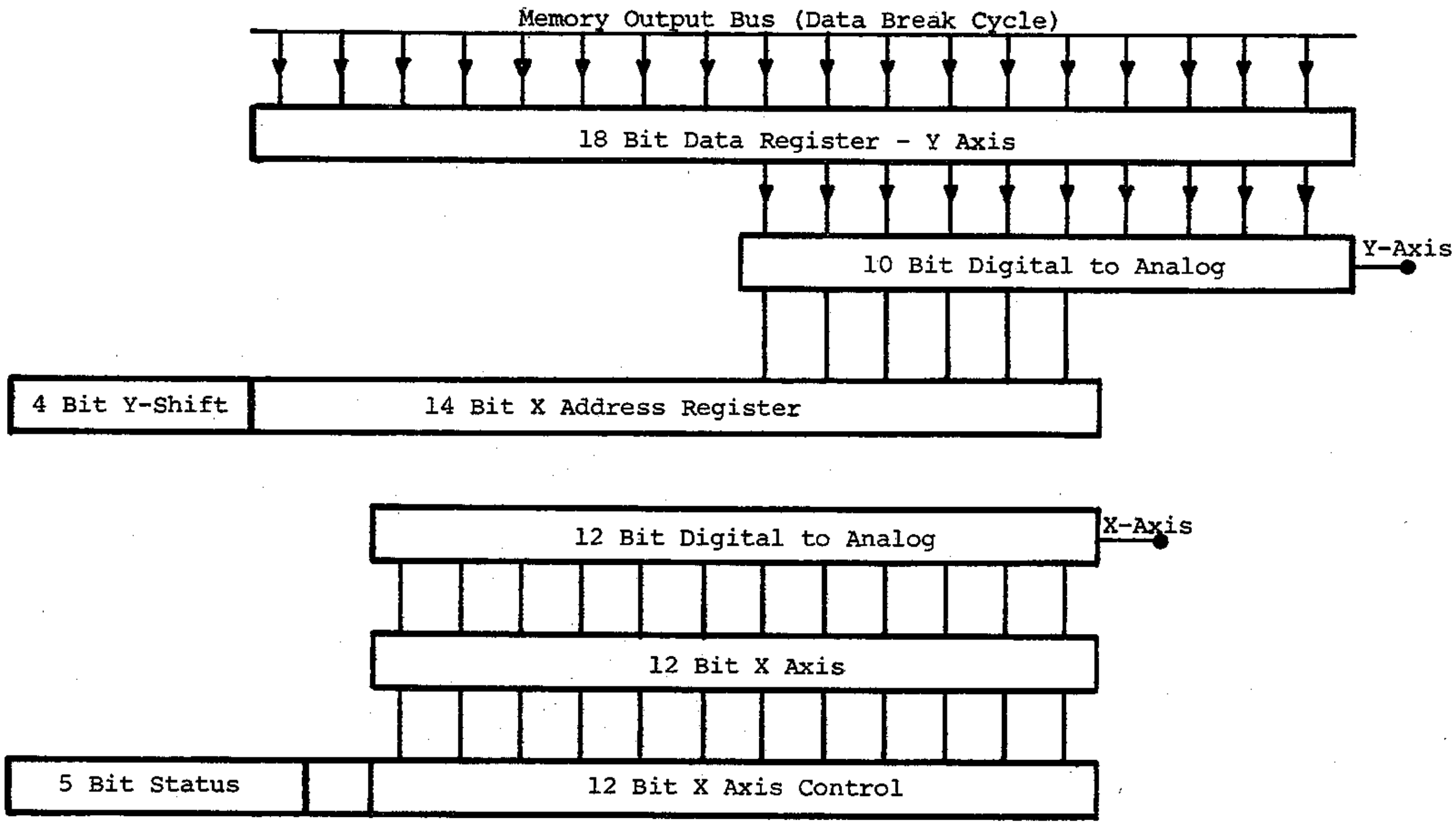


**FIGURE 4. DISPLAY CONTROL REGISTERS**

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MARK | 1 | 0 | 0 | 0 | 0 | Ø | X-AXIS MARKER VALUE | | | | | | | | | | | |
| ZERO | 0 | 0 | 0 | 1 | 0 | Ø | X-AXIS SETTING | | | | | | | | | | | |

X-AXIS AND MODE CONTROL STATUS

| | 0 | 1 | 2 | 3 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MARK | Ø | Ø | Ø | Ø | Ø | 0 | 0 | 0 | 0 | 0 | 0 |
| ZERO | Ø | Ø | Ø | Ø | 0 | Y-AXIS VALUE ÷ 2**4 | | | | | |

X-ADDRESS BIT ASSIGNMENT

**FIGURE 5. STATUS FOR MARK AND ZERO MODES**

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REGION | MARK | PLOT | DISP | ZERO | FLAG | SPARE | MUST BE SET | | | | | X-AXIS DATA MASK | | | | | | |
| 32 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 128 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 256 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 512 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 1024 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 2048 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 4096 | 0 | 0 | 1 | 0 | 0 | Ø | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

X-AXIS CONTROL BIT ASSIGNMENT (DISPLAY)

| Y-SHIFT | X-AXIS STARTING ADDRESS |
|---|---|

X ADDRESS CONTROL WORD ASSIGNMENT (DISPLAY)

**FIGURE 6. DISPLAY MODE STATUS**

# APPENDIX A

## TYPICAL USES OF PULSE HEIGHT ANALYSERS

Pulse height analysis systems are used to obtain spectral energy distributions of a large number of nuclear particles or rays. A common usage is the spectral analysis of gamma ray emission. This emission has a linear structure and, when accumulated using currently available diode detectors, this linear structure is accurately maintained so that the resulting spectra represent a true distribution of nuclear transition energies. These distributions vary markedly depending upon the source of the emission with each isotope producing its own characteristic spectrum basically consisting of a series of fine lines. A typical spectrum for cobalt-60 using a Ge-Li gamma spectrometer is shown in Figure A1.

Tables of decay schemes of the various isotopes and some of their excited states have been compiled for a number of years using pulse height analysis techniques and these tables are used extensively to identify particular anomalies in collected spectra from samples.

Some of the uses of pulse height analysis systems are:

(1) Activation Analysis. When a sample is required to be analysed it may not necessarily emit any nuclear particles or rays. If, however, this sample is bombarded with a strong source of radiation such as neutrons the isotopes present may capture one of the bombarding particles. This results in a change of isotopic state or results in an excited state of the same isotope. The subsequent decay of these states can be analysed using a spectrometer connected to a pulse height analyser. The spectrum obtained can then be compared with known decay schemes listed in the decay tables and the parent isotopes can be identified and their intensities measured; from this the amount of isotope present in the original sample can be calculated. This technique is exceedingly laborious and requires large computer codes to do the sorting unless the sample is being analysed for a particular element only.

(2) Impurity Measurement. The above technique can be used to detect and estimate very small amounts of impurities in a product where these impurities can affect performance, etc.

In this case analysis or activation analysis is vastly simplified as only a few peaks have to be positively identified.

(3) Standardisation. Sources can be counted using a pulse height analyser in certain cases. Normally, standardisation is carried out on a one pulse one count basis, but when other emitters such as daughter products in decay schemes are present then a spectral analysis can sort which counts belong to which groups.

The same techniques apply to many fields where precise energy data is required. The pulse height analyser has become a much more useful tool with the development of the semiconductor diode spectrometers which enable separation of quite close peaks and, because of this, show many more anomalies which would have been lost with a halide scintillation system. An example of the fine line structure obtained using a Ge-Li spectrometer is shown and compared with a NaI spectrometer for silver 108 and 110 (Figure A2). The NaI spectrum has a much higher count per channel because of the much higher efficiency of this type of spectrometer.

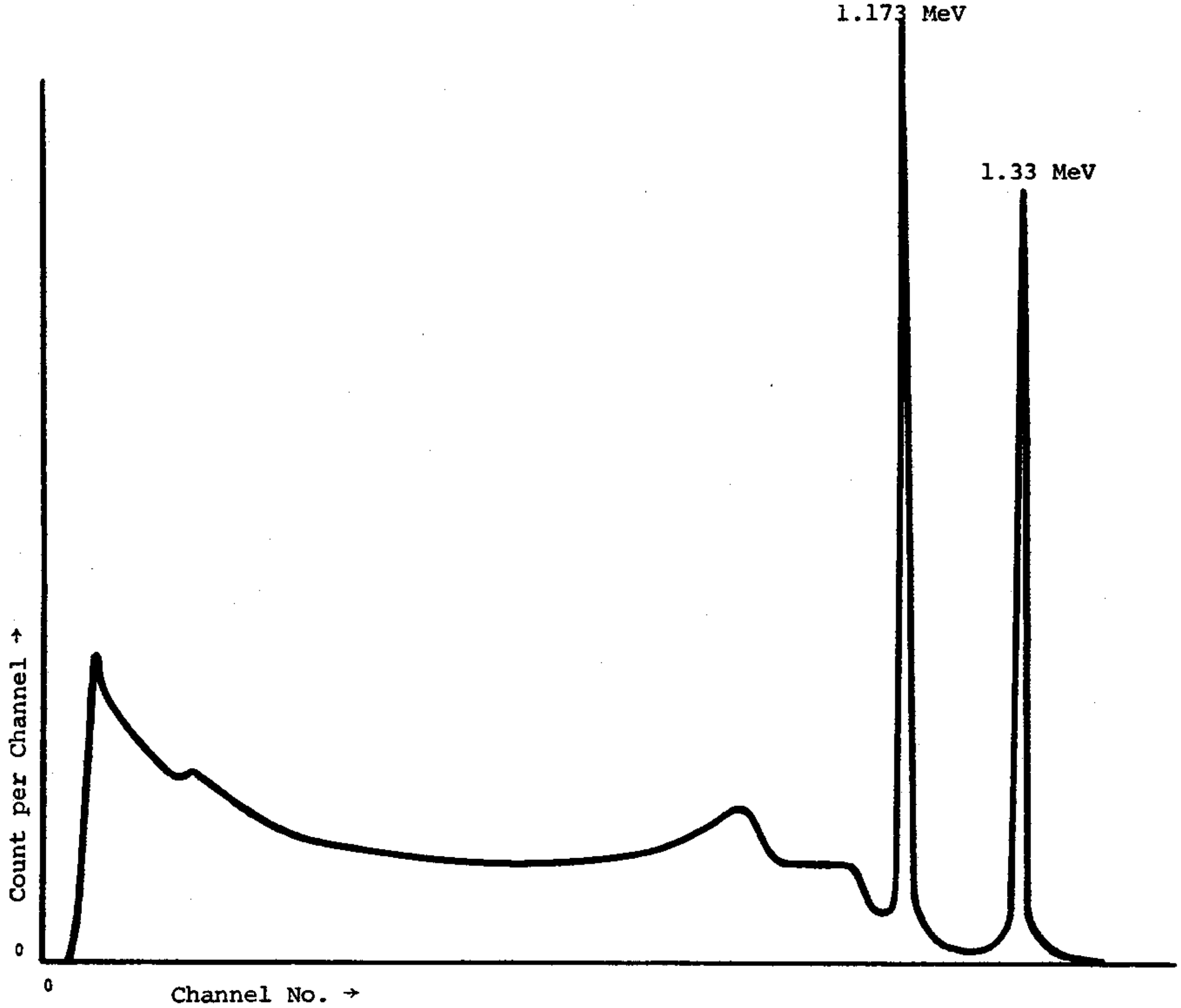


FIGURE A1. COBALT-60 SPECTRA USING GeLi DETECTOR

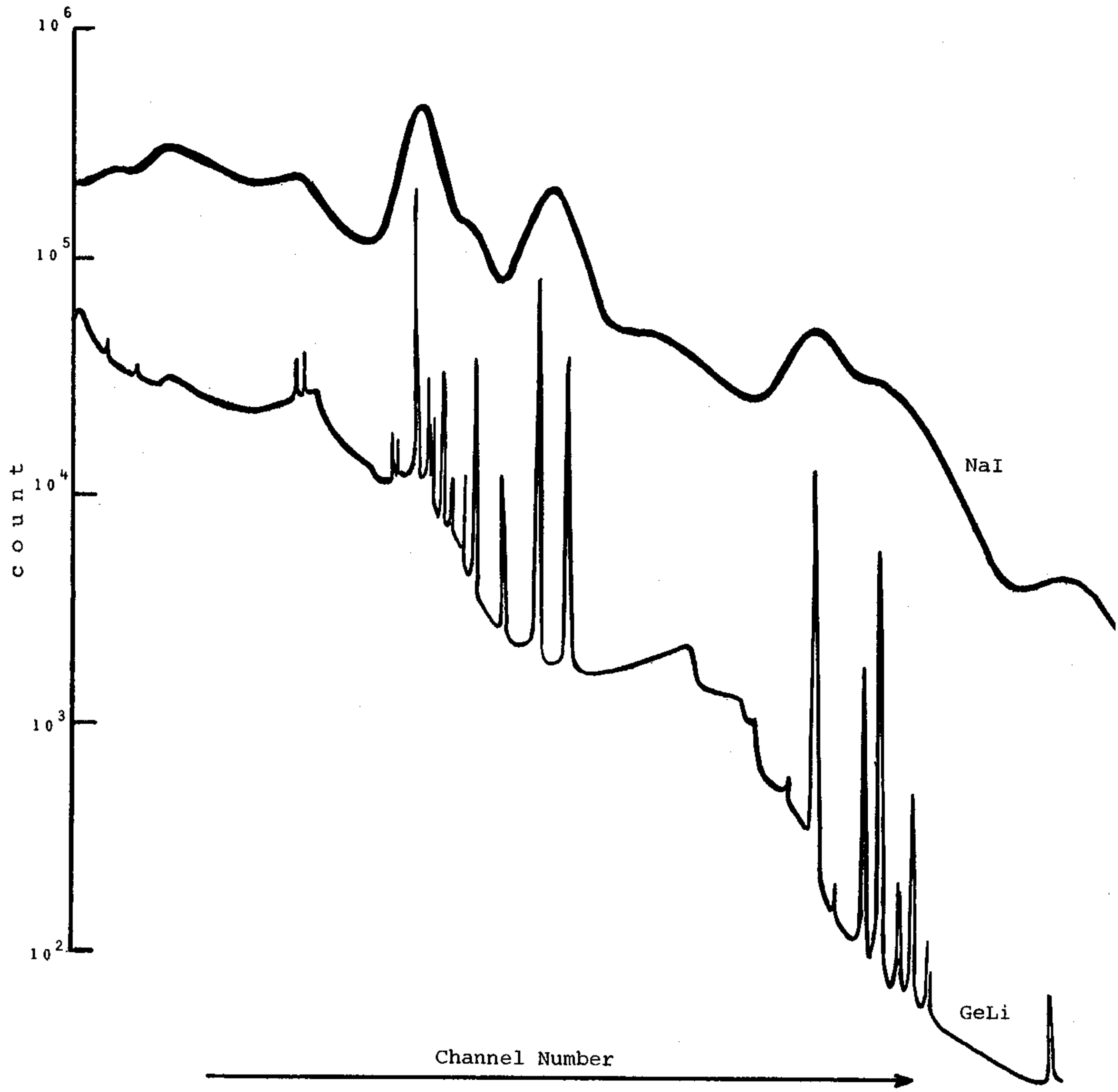


FIGURE A2. SILVER-108/SILVER-110 SPECTRUM USING NaI AND GeLi SPECTROMETERS