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THE UNIVERSITY OF ALBERTA

A MULTIPLE PHOTODIODE ARRAY DIRECT READING SPECTROMETER  
FOR EMISSION SPECTROSCOPY

by

ROBERT G. EVANS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH  
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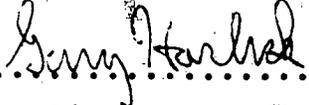
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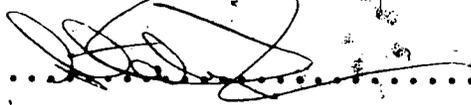
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## ABSTRACT

The replacement of the photographic spectrograph by the electronic direct reader has greatly improved the quality of elemental analysis by atomic emission spectroscopy. In making the change, two useful characteristics of the spectrograph were lost. These were the relative ease with which new analytical problems could be tackled, and direct information about the background against which the intensity of a spectral line was measured. Both of these losses were due to the replacement of a detector measuring a continuous spectral range by a series of discrete, single wavelength detectors.

The photodiode array is a solid state imaging device, and when it is used as a detector as a replacement for the photomultiplier tube, it allows the measurement of a spectral window rather than just a single line. This restores the versatility and knowledge of the spectral background previously lost.

The design, construction and testing of a direct reading instrument based on short segments of photodiode array are described. Detection limits for the array are shown to be approximately equivalent to those of the photomultiplier tube system.

A technique is developed for controlling, and receiving data from several photodiode arrays with a single microcomputer..

The new instrument demonstrates solutions to some of the background problems of the direct reader. Its versatility as an analytical tool is demonstrated by its rapid adjustment to solve an analytical problem.

Finally, the problems associated with the new system are described and suggestions for their solution proposed.

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## CHAPTER I

### INTRODUCTION

#### 1. The Direct Reader

The direct reader is a spectrometer for determining the concentrations of several elements by simultaneous, direct measurement of the intensities of their atomic emission spectra.

The spectral intensities are measured electronically and converted to numerical values which are related to the elemental concentrations; all without the delay of further processing. This is in contrast to the spectrograph which requires the time-consuming processing of photographic film and subsequent skilled interpretation.

The electronic recording of atomic emission intensities was forecast by Harrison in 1940 [1]. Early experiments were made by Duffendack in 1942 [2] who found that a Geiger counter could be made to respond to that part of the ultra violet region with wavelengths below 260 nm. By 1945 Saunderson [3] was investigating arc spectra using eleven photomultiplier tubes.

The photomultiplier tube based direct reader, as illustrated by Figure 1, has become the standard instrument for the routine measurement of atomic spectral intensities. To do this, it had to show considerable advantages over the already established photography based spectrograph. These were:-

- i. The analytical results were available immediately.
- ii. The results were obtained by a less skilled operator.
- iii. A higher rate of sample throughput.
- iv. Superior accuracy.
- v. Superior precision.
- vi. Greatly increased linear dynamic range.

The immediate availability of analytical results is very important to metal processors who require such information before making a casting [4]. The lower level of skill needed in the operator combined with the higher throughput of samples reduces the cost of analysis [4].

The superior accuracy, precision and linear dynamic range of the direct reader changed atomic emission spectroscopy from a qualitative, or at best a semi-quantitative, analytical method to a quantitative one. The accuracy improved from about 10% for the spectrograph, with the use of internal standards and a skilled operator, [5] to 1% [6]. Relative standard deviations improved from

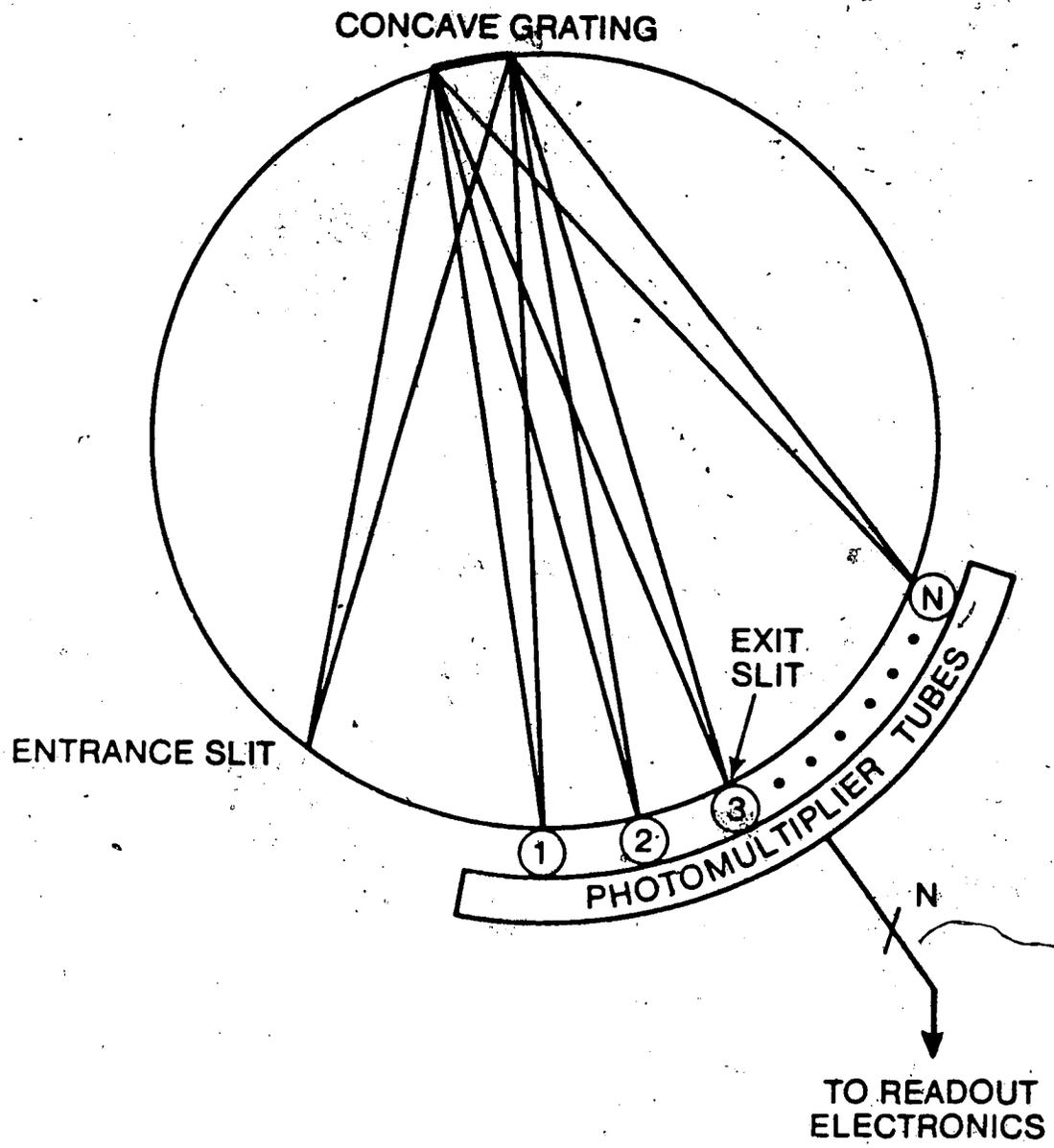


Figure 1. The photomultiplier tube based direct reader.

a few percent [7] (about 10%) to 1% or less. The linear dynamic range, with respect to intensity measurement, of the spectrograph is limited to one order of magnitude as the intensity of a spectral line is measured photographically. In contrast, the photomultiplier tube has a linear dynamic range of seven orders of magnitude so that the linearity of the direct reader is generally limited by that of the spectral emission source.

The direct reader has three major disadvantages when compared to the spectrograph. These are due to the replacement of a detector covering a continuous spectral range by a series of discrete detectors. A photographic plate capable of recording 10,000 resolution elements is replaced by a series of exit slits backed by photomultiplier tubes capable of recording only 30 to 60 resolution elements (one per tube). These disadvantages are:

- i. Limited and restricted wavelength coverage.
- ii. Lack of versatility.
- iii. Limited background correction.

2. The Versatility Problem

With the spectrograph, detection of an additional element involved the selection and subsequent interpretation of a suitable spectral line within the

wavelength range of the instrument. With the direct reader it is much more difficult.

The placing of the exit slits in the focal plane has to be very accurate as they are only 20-50  $\mu\text{m}$  wide and have to be centred on the analyte line. Addition of a detector for a new element without adverse effect on those already in place requires technical input from the instrument's manufacturer. The close packing of the exit slits is limited by the need for the slits to have boundaries and particularly by the absolute width of the photomultiplier tubes. Although a pair of closely spaced spectral lines can be separated by accurately positioned plane or prism shaped mirrors, close packing of the detectors is a limiting factor in the selection of spectral lines. The spectrograph is a general purpose instrument. The direct reader is almost always custom built. The user has to specify the elements to be analyzed for, or that are likely to be present in all matrices to be investigated, when ordering the instrument. The instrument supplier then must design the direct reader focal plane array to suit, taking into account his own limitations.

In order to return partially to the concept of versatility, manufacturers have taken to fitting the focal plane with slits or slit holders for most of the elements

usually sought after, and supplying detection systems and detection system optics, such as mirrors and wavelength selection filters, for those elements specified by the customer. In order to give the user some versatility, at least one manufacturer has combined a monochromator with a direct reader. Part of the light generated by the spectral source enters a scanning monochromator that can be preset to any particular wavelength by an operator [8]. The single photomultiplier tube of the monochromator is coupled to the direct reader electronics as an effective extra channel.

### 3. The Background Correction Problem

Another major disadvantage of direct readers is their lack of data on background radiation against which the strength of the emission line can be measured.

The background radiation has two sources:

- i. Stray light.
- ii. Spectral interference.

#### 3.1 Stray Light

Stray light has been broadly defined as "The unwanted radiation that reaches the detector in unintended ways" [9]. It is caused by defects in the instrument which may be in the quality of the components in the rest of the instrument.

When a master grating is made on a ruling machine, the diamond cutting tip is advanced by a lead screw. Imperfections in the lead screw give periodic errors in the spacing of the grooves on the grating and these are reproduced in the replicate gratings. This causes the formation of secondary images, known as Rowland ghosts, that are spaced symmetrically about the parent line [10]. If the ruling is subjected to an external periodic vibration, the grating forms other secondary images called Lyman ghosts at a large distance away from the parent line [10].

Light is scattered from the surface of the grating. Near scatter (below 5 nm from the parent line) is the effect of random disturbances of the ruling machine. Far scatter (more than 5 nm from the parent line [9]) is due to microscopic imperfections in the grooves or the grating blank. The diamond tipped cutter of the ruling machine may deform the edges of the grooves as it makes them, by pushing up the material displaced by the cutter, and this roughness adds to the far scatter [11]. Some gratings are now being made without the use of ruling machines by photographically recording the interference pattern obtained from two beams of monochromatic (laser) light [10]. Such holographically recorded gratings do not exhibit ghosts and consequently have much lower stray light levels than ruled gratings [9,10].

Apart from the grating, there are other causes of stray light inside the direct reader light-proof box. Reflection of both primary (undiffracted) and diffracted light off the interior surfaces of the system can cause far scatter and general background stray light. Because they are directly in the path of the spectral line, the edges of exit slits and the photomultiplier tubes themselves can cause scatter [9].

Instrumental line broadening is caused by the finite width of the slits, optical misalignments and optical aberrations. This can cause overlap of closely spaced spectral lines [9].

### 3.2 Spectral Interferences

Spectral interferences are generated when light generated by a spectral source is processed by an ideal grating. There are two classes of spectral interference:-

- i. Produced by the grating, where the interfering radiation will have a different wavelength to that of the analyte line.
- ii. Produced in the spectral source so that the interfering radiation has the same wavelength as the analyte line.

The grating produces multiple orders of spectral lines and these are routinely used by direct reader designers to help overcome detector spacing problems.

Wavelength selective transmission filters are used to differentiate between the various principal orders. The grating also forms secondary interference maxima of much lower intensity than the principal ones. These may become significant in the future as instrumental defects are eliminated but at present they are of little significance [12].

Spectral interferences produced in the spectral source are a much more serious problem as they have the same wavelength as the analyte line but are generated by other species. The other species can be part of the carrier or excitation system of the source, or they may be concomitant species supplied by the analytical sample matrix. Carrier generated interferences are source dependent and may be of a molecular nature. For example, cyanogen bands may be generated by a DC arc source,  $C_2$  and CH bands by a flame source and nitric oxide bands by an inductively coupled argon plasma. Additionally, all systems where an aqueous solution of the sample is nebulized generate hydroxyl bands.

The atomic emission lines for the elements in the carrier also occur in the spectrum, often with variable intensities. Examples are carbon lines in DC arc and argon lines with the ICP.

Concomitant generated interferences are of several kinds. These are direct line overlap, wing overlap, and, with the inductively coupled argon plasma source, recombination continua [13]. Direct line overlap occurs where a concomitant element has a spectral line too close to that of the analyte for the instrument to resolve. Wing overlap occurs when the concomitant and analyte lines can be resolved but the spectral profiles of the lines overlap sufficiently for the intensity of the analyte line to include some portion of that of the concomitant. Recombination continua are generated by the radiative recombination of certain metal ions with the high concentration of electrons in the argon plasma. Strong continua are formed by magnesium, calcium and aluminum that alter spectral base lines below 250, 302 and 220 nm respectively [12].

The major problem of concomitant generated interference is that the concomitant concentrations are, like those of the analyte elements, part of the unknown in the analyte sample. When concomitant species are in much higher concentration than the analyte, they can cause special problems. A spectral line of an element, present at a trace level, can suffer overlap from a minor spectral line of the concomitant that only becomes significant because of the great differences in the concentrations.

Large concentrations of strongly emitting concomitants are also the major sources of instrumental stray light.

In summary, the light intensity detected for the analyte spectral line may not be proportional to the analyte concentration because it is measured against an unknown and variable radiative background.

#### 4. Current Background Correction Methods

Current methods of correcting for background radiation can be described as either off-peak or on-peak methods.

##### 4.1 Off-peak Methods

Off-peak methods are made by sampling the background on one or both sides of, an analyte line, just outside the instrument band pass.

For example, a direct reader with an exit slit 50  $\mu\text{m}$  wide and a reciprocal dispersion of 0.53 nm per mm would have a band pass of 0.0265 nm and the background would be sampled at line  $+0.034$  nm [14]. The correction is made by altering the angle at which the incident light meets the grating, so that all of the detector channels are effectively shifted off all of the analyte lines by the same distance, and then taking a second set of intensity measurements.

One of two mechanisms is generally employed. In one, a quartz refractor plate located just behind the entrance slit of the direct reader is rotated to shift the effective position of the slit sideways with reference to the grating. This requires a high degree of precision in the control of the angle change and may change the level of light transmitted due to the change in reflectivity at the plate surface as it is turned [15]. The other method involves physically moving the entrance slit sideways. This again has to be carried out with precision and gives rise to the problem that the same portion of the plasma source is no longer being sampled. It has been shown by Blades and Horlick [16] that the intensity profile of the spectral lines emitted from the plasma is laterally position dependant so the background measurements may be inaccurate.

Off-peak correction requires an extra measurement at each detector. As these must be at different times, it requires that the source be a stable one such as an inductively coupled plasma using nebulized sample solutions. It corrects for continuum radiation and general stray light. The species causing the background need not be known. It cannot correct for spectral line overlap and is very vulnerable to the presence of an unanticipated line interference on any of the analyte channels.

#### 4.2 On-peak Corrections

On-peak corrections are more complicated. Prior to the analysis, the response of all detector channels is obtained to a range of concentrations of the concomitant elements. All likely concomitants must be considered. Working curves are prepared for all channels in terms of apparent concentration of analyte against actual concomitant concentration. During the actual testing of the analytical sample, measurements of the concomitants are obtained on separate channels and the corrections calculated from the working curves and subtracted from the analyte values. However, in order to do this, the interfering concomitant must have its own channel on the direct reader. That is to say that it had to be considered at the time the instrument was ordered. This is the reason for specifying all the analytical matrices to be tested when the focal plane array is being designed.

Provided that all of the concomitants are determined, on-peak correction is more accurate than the off-peak method. It is the only way to correct for direct spectral overlap. It requires that the position of all the exit slits be stabilized with respect to the diffraction grating and the entrance slit. This requires that the temperature of the instrument be thermostatically controlled.

The background correction problem was foreseen while the instrument was in the early stages of development. Hasler and Dietert [4] forecast the problem in 1944 and Saunderson [3] attempted background measurements in 1945 by using a wire to divide the exit slit into two parts, and diverting the background for measurement.

The off-peak correction method requires two or three sets of measurements for each analysis. An alternative is to scan across each analyte line to get a profile of the line and its background in the same manner as the densitometer readout of a spectrograph photographic plate. Brehm and Fassel [17] used such a scanning technique in 1953 because of problems in locating spectral lines especially when the temperature of the instrument changed. A similar approach has led to the development of a possible rival to the direct reader, the slew-scanning monochromator. Here a single exit slit and photo-multiplier tube is used and spectral lines are detected sequentially rather than simultaneously. The grating of a monochromator is quickly turned so that the detector receives each line in turn [18]. The rotation of the grating is fast (slew) from one line to the next and then slow as the profile of the line is scanned. It then slews to the next line and so on. The system depends on accurate and fast control of the grating rotation during

both slew and scan processes. Because it acts sequentially, it requires a constant analyte signal such as that given by the inductively coupled argon plasma (ICP) using analyte solutions. It cannot handle transient signals.

A major research field in ICP spectrometry is the removal of the sample digestion and dilution step from the analytical procedure by direct sampling of solid analytes. Instead of the steady signal level obtained from a constant analyte solution flow, these methods give a quick intense burst of signal. All analyte spectral intensities must be measured simultaneously and this requires the direct reader used without the option of off-peak correction methods and certainly not the slew-scan system.

##### 5. An Alternative Approach

In order to regain the versatility and knowledge of background levels possessed by the spectrograph the photographic plate must be replaced by a spatially continuous detector, such as an electronic imaging device, not by a series of discrete single measurement detectors.

Electronic image detectors are available configured in either one or two dimensions. The use of a single grating as a spectral dispersion device suggests the use

of a one dimensional imaging device such as the linear photodiode array. Two dimensional devices such as the Vidicon are more suitable for the echelle spectrometer, where a coarsely ruled, blazed grating generates high orders of spectra that are then order sorted by a crossed prism to a two dimensional image pattern. Such a system has been built by Wood [19].

Vidicons are read out using an electron beam directed by scanning electric field coils and are subject to lag and bloom. Lag involves the carryover of signal from one readout scan to the next due to incomplete recharging of the sensor during readout [20,21]. Bloom involves the transfer of a very intense signal over adjacent channels due to the overspill of photon generated charge [22].

On the other hand, linear photodiode arrays utilize solid state switching readout. Because they are fully recharged in less than 1  $\mu$ s, they do not exhibit lag [23]. Blooming is also less of a problem. It is suggested by Talmi and Simpson [23] that charge spillover with diode arrays is a gradual process, proceeding one diode at a time.

The self scanning linear photodiode arrays have been used for spectrochemical measurements for several years [24]. Some of the early applications were in astronomy where they were applied to low light level

spectrophotometry [25]. All of these applications have involved one (or at the most two) [26] photodiode arrays located in permanent fixtures. Diode arrays are relatively small, flat devices. The largest array of the "S" series designed for spectroscopy has 1024 diodes covering a sensor length of 25.6 mm. Consequently a single array cannot cover much of the focal plane of a direct reader which may be 1 m in length. Even if much longer arrays were available, they would have to be curved to conform to the shape of the focal plane of the direct reader. Several small, moveable arrays must be used instead.

The concept of such an instrument, illustrated by Figure 2, is given below.

A normal direct reader optical system is used in which light from an external spectral source passes through a single entrance slit and illuminates a single concave, reflecting, diffraction grating. This grating both wavelength disperses and refocusses the light into a series of wavelength separated images of the entrance slit that are focussed on a curved focal plane. In a traditional direct reader, these images would be individually selected by a series of exit slits and the light from each transferred by simple secondary optics to the photomultiplier tube detector. In the conceived

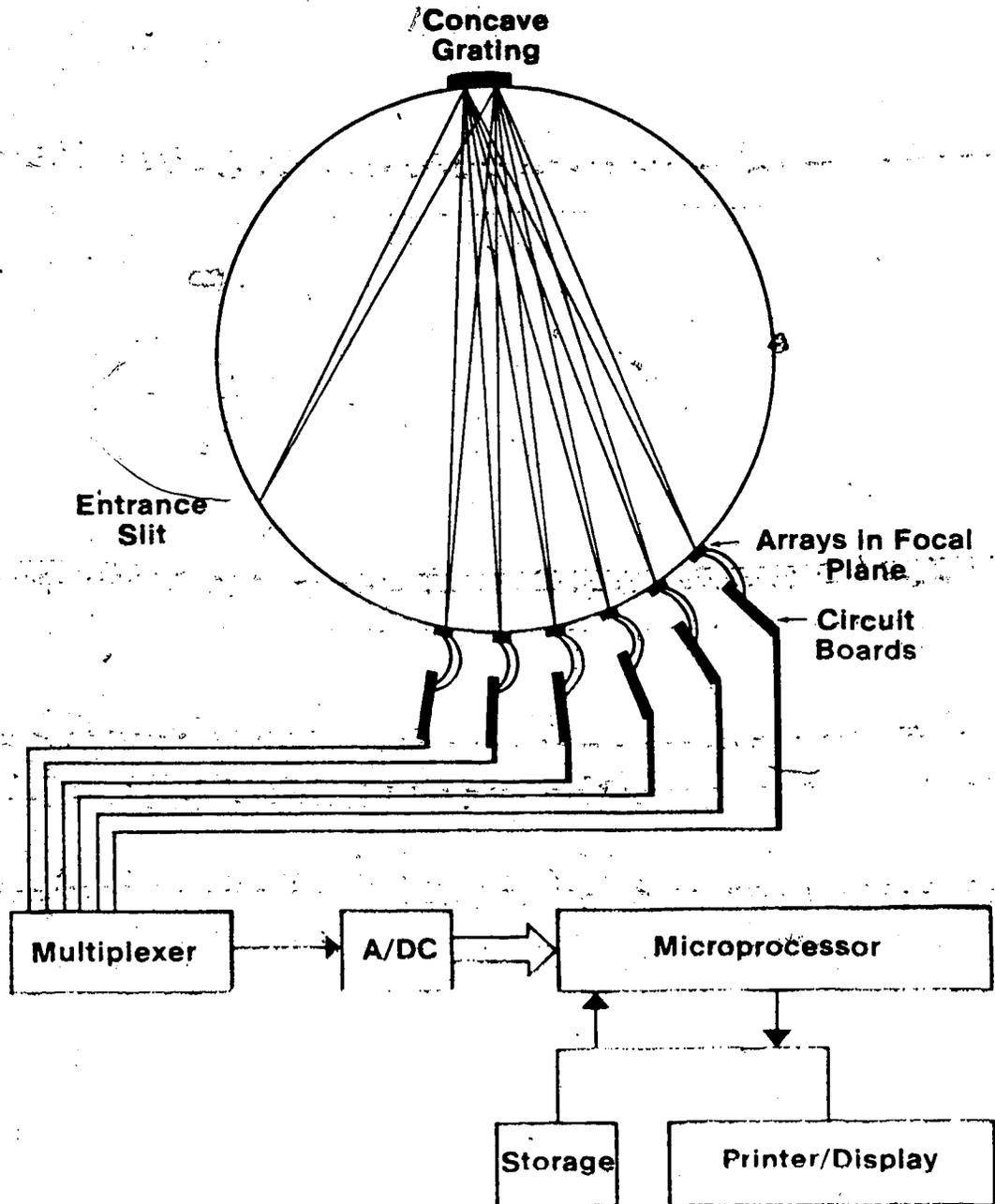


Figure 2. A diode array based direct reader.

system, the secondary optics are discarded and short photodiode arrays placed directly in the focal plane. The diode arrays are positioned along the focal plane so that each one detects a spectral window which includes atomic emission of one, or more than one element. The arrays are mounted with the longest dimension of the diodes (height) parallel to the entrance slit images and each individual diode samples a different wavelength. The whole array thus gives spectral intensities over a wavelength window including the analyte signal and the neighbouring background.

Each diode array is individually controlled and its data output individually processed. In order to achieve versatility the diode arrays are capable of being moved anywhere on the direct reader focal plane subject to the restriction of their size and that of their immediate fittings.

The instrument can be adjusted to new applications quickly because the window of the photodiode arrays makes spectral line location fast and easy. Backgrounds can be measured directly in the same analytical determination as the analyte signals. Signals from different photodiode arrays can be interrelated to correct for direct spectral overlap. Once the arrays have been positioned, there are no moving parts to consider. Transient signals are measured as easily as steady signals.

This project covers the design and construction of such a system and its evaluation as a direct reading spectrometer.

## CHAPTER II

### THE BASIC COMPONENTS OF AN EXPERIMENTAL DIRECT READER

A direct reading spectrometer has the following basic parts.

1. A source of spectral information.
2. A system for dispersing light according to its wavelength.
3. A series of light detectors and transducers.
4. A data handling system.

#### 1. The Source of Spectral Information

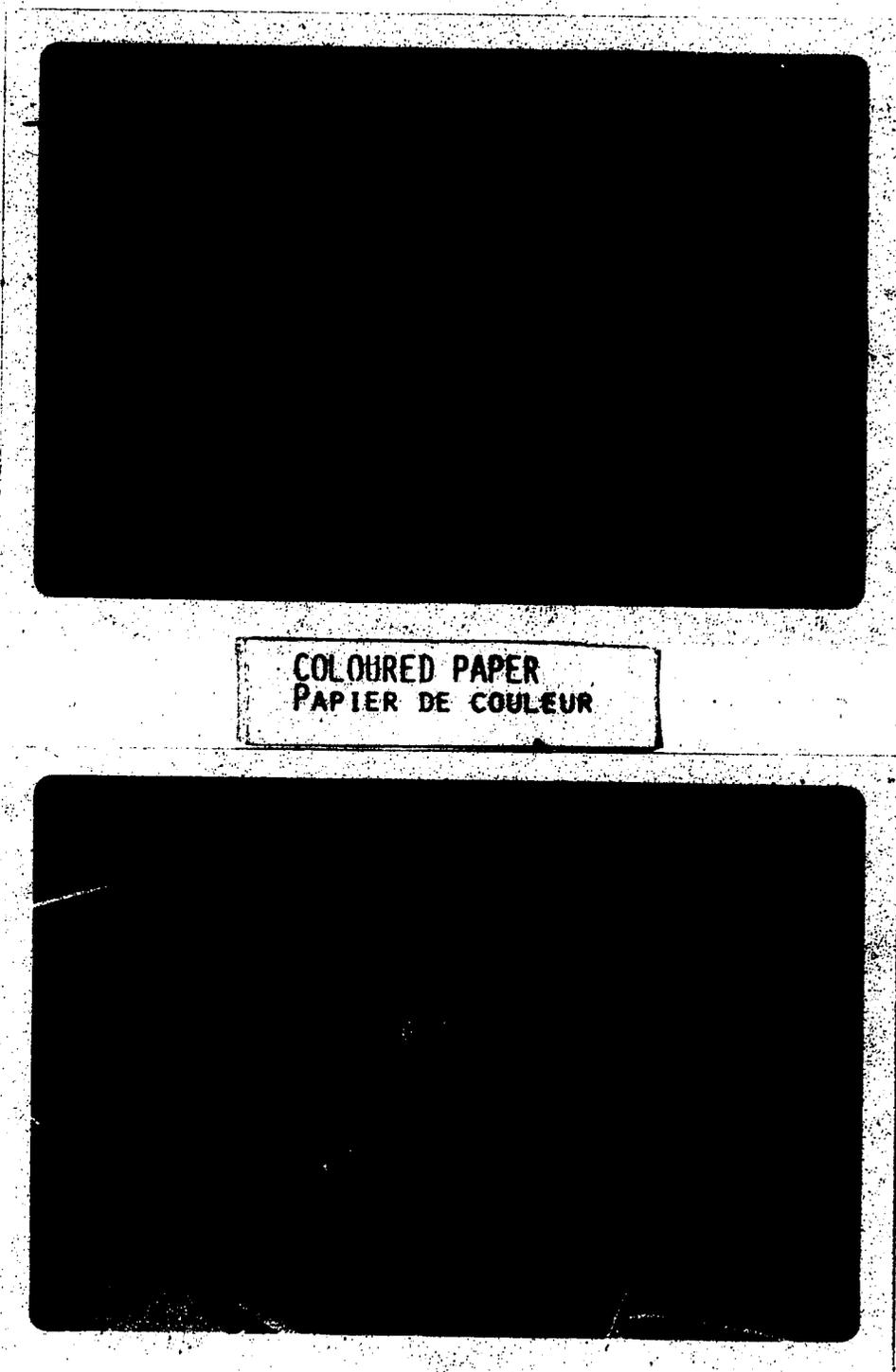
The main spectral source was an Inductively Coupled Argon Plasma (ICP) as described in Appendix 1. Analyte sample was introduced into the plasma using a glass concentric (Meinhard) nebulizer. Because the ICP was not always available, or desirable, three other spectral sources were occasionally used. These were:-

- i. A Metrologic, MC 650, helium-neon laser, giving an intense spectral line at 632.8 nm.
- ii. An Osram Spectralampe, cadmium discharge lamp.
- iii. Several atomic absorption-type hollow cathode lamps.

## 2. The Light Dispersion System

The dispersion system was originally a Jarrel-Ash Company, Compact Atomcounter that had been designed prior to 1961. The original arc type spectral sources, the photomultiplier tube detectors and the measurement electronics were removed and discarded. The light-proof (dark) box was mounted on a steel frame so that the entrance slit was 51.5 cm above the floor. This was to make it compatible with available spectral sources that are mounted at that height. The following fittings are retained with the light-proof box:-

- i. A 25  $\mu\text{m}$  wide by 1.8 cm high fixed entrance slit with a sliding shutter mounted in front of it and a quartz refractor plate mounted behind it.
- ii. A concave reflective diffraction grating 6.3 cm wide by 4.1 cm high with a radius of curvature of 1.5m. The grating has 1,180 grooves per mm and is blazed for 360 nm.
- iii. The exit slit mounting rack in the approximate position of the focal plane of the direct reader and the photomultiplier tube mounting racks (Photographs 1 and 2). The exit slit mounting rack has a metric, steel measuring tape attached as a positioning guide.



Photographs 1 and 2. The focal plane area of the direct reader.

The configuration is known as the Paschen-Runge mount and is based on the Rowland circle principle (Figures 1 and 2). This uses a concave reflective diffraction grating with a radius of curvature equal to the diameter of the Rowland circle. Thus the distance from the grating to the spectral focal plane opposite the grating is 1.5 m. Light from a point source on the circumference of the Rowland circle is dispersed and re-focussed by the concave grating to images along the circumference of the same circle [27,28]. It is a simple optical system as it does not require any optical devices within the instrument other than the single concave reflective grating. This allows full freedom in the placing of detectors.

The reciprocal dispersion is given by:-

$$\frac{d\lambda}{dl} = \frac{a \cos \beta}{nr}$$

where:-  $\frac{d\lambda}{dl}$  = rate of change of light wavelength with  
change in position around the Rowland circle

a = grating ruling interval

n = spectral order.

r = radius of curvature of the grating

$\beta$  = angle of dispersion of a particular  
wavelength of light.

Hence our instrument has a reciprocal dispersion of 0.565 nm per mm directly opposite the grating and 0.540 nm per mm at an angle of dispersion of  $17^\circ$  (the limit of the useful arc of the instrument). The spectral range in first order is from 200 nm to 760 nm based on the geometry of the light-proof box.

### 3. The Light Detector and Transducer

#### 3.1 Description

The Reticon "S" series self-scanning photodiode arrays provide individual sensor elements every 25  $\mu\text{m}$ . When this is coupled with the dispersive system, the spectrum is sampled at 0.0135 nm to 0.0141 nm intervals. This is less than the width of the image of the entrance slit at the focal plane of the dispersive system. The "S" series arrays were specially developed for spectroscopic work having an aspect ratio of 100:1 (2.5 mm high by 25  $\mu\text{m}$  spacing) so that they can sample large portions of the slit images in a spectrometer. Previous types of photodiode arrays were limited to a detector height of 0.6 mm [29].

Six 128 element arrays were obtained (RL128S). These were 2.72 cm long with a sensor width of 3.2 mm and were mounted as a standard 22 pin integrated circuit. Six evaluation circuits #RC1024S-1 were obtained to drive and handle the outputs for each array.

### 3.2 Mode of Operation

The diodes consist of bars of diffused p-type silicon semiconductor set in an n-type silicon substrate [30]. The whole detector is photosensitive. Light falling on a p-type semiconductor bar generates hole-electron pairs that directly affect the charge on that p-type bar. Light falling on the n-type semiconductor generates hole-electron pairs whose effect is shared by the adjacent p-type bars. The nearer p-type bar takes the larger portion (see Figure 3).

The diodes are operated in a storage mode. The p-n junctions are reverse biased, that is to say, the n-type substrate is held at a higher voltage than the p-type bars. In this mode the junction acts as a capacitor. During the reset procedure the p-type bars are grounded so that the capacitor becomes fully charged. The p-type bars are then isolated from ground for a period of time called the integration time.

Over this time period, the charge on the capacitor will be reduced by the reverse current flowing in the photodiode. This reverse current is due to both the photo-electrically generated current and to dark fixed pattern signal. At the end of the integration time, the p-type bars are connected to a previously grounded video line. The charge on the p-type bars divides between the

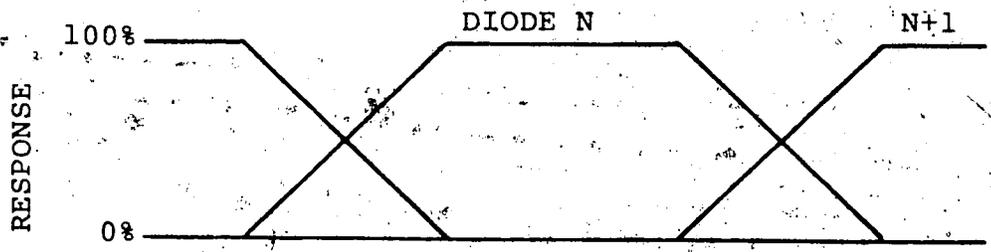
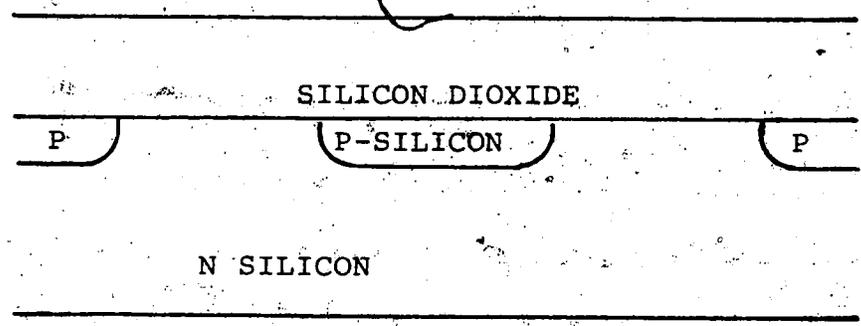
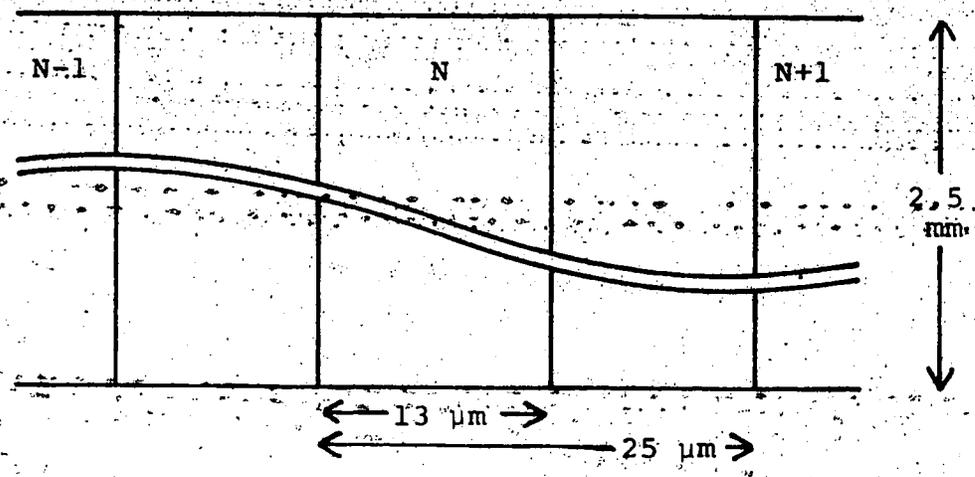


Figure 3. Sensor geometry and response function of a photodiode array [30].

diode and the video line and the resulting change in the video line voltage is detected. As the n-type substrate is still held at the bias voltage (+5 Volts) the readout operation also recharges the capacitor for the next integration.

The full charge on the capacitance is 14 pC. When this has been fully discharged either by light or by the dark fixed pattern, the diode is termed saturated.

### 3.3 Spectral Response of the Array

The quantum efficiency of the photodiode in terms of hole-electron pairs generated per photon received is wavelength dependent with a maximum of 80% at 650 nm [30]. A plot of responsivity against wavelength is shown in Figure 4. Responsivity is the ratio of the charge lost at saturation to the saturation light exposure and has a maximum of  $2.8 \times 10^{-4}$  coulombs per joule per  $\text{cm}^2$  at 750 nm. It decreases rapidly towards both the ultra-violet and the near infrared. The quantum efficiency curve would appear higher than the responsivity curve at lower wavelengths due to the higher energy of the lower wavelength photons. Recently data has been published [23] to show that the quantum efficiency decreases to a minimum of 35% at approximately 270 nm and then increases to a new maximum of 57% at 200 nm.

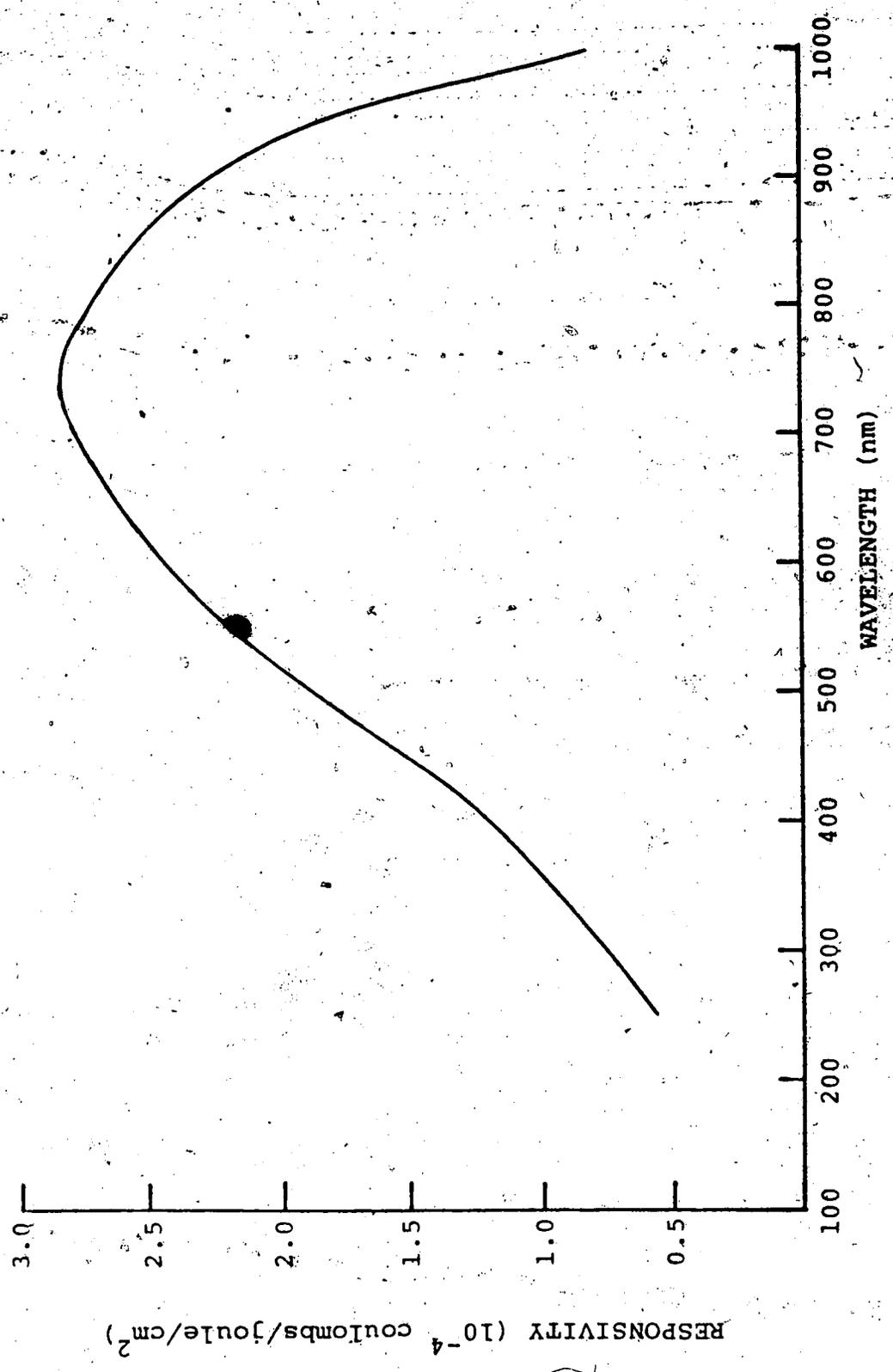


Figure 4. Typical spectral response of a photodiode array [30].

### 3.4 Readout

An equivalent circuit for the array switching system is given in Figure 5 [30]. Each cell consists of a photodiode and a dummy diode. Certain switching transients are capacitively coupled into the video lines. These same transients are introduced into the video lines of the dummy diodes and are eliminated by differential processing of the active and dummy video signals.

Scanning of the array during readout is controlled by two independent shift registers, one to address the odd numbered diodes and the other the even ones. Each shift register is driven by two phase clocks and scanning is initiated by a start pulse at the end of the integration time. The start pulse and the clock pulses are not generated on the diode array but are supplied and controlled by auxiliary devices. The use of separate switching and signal handling systems for odd and even diodes is a potential source of variability in the readout signal processing that has to be carefully controlled.

### 3.5 The Dark Fixed Pattern Signal

Dark fixed pattern signal decreases the charge on the diode capacitance and has two origins [31]: (i) the integrated dark current due to the thermal generation of hole-electron pairs and (ii) cross coupling between the

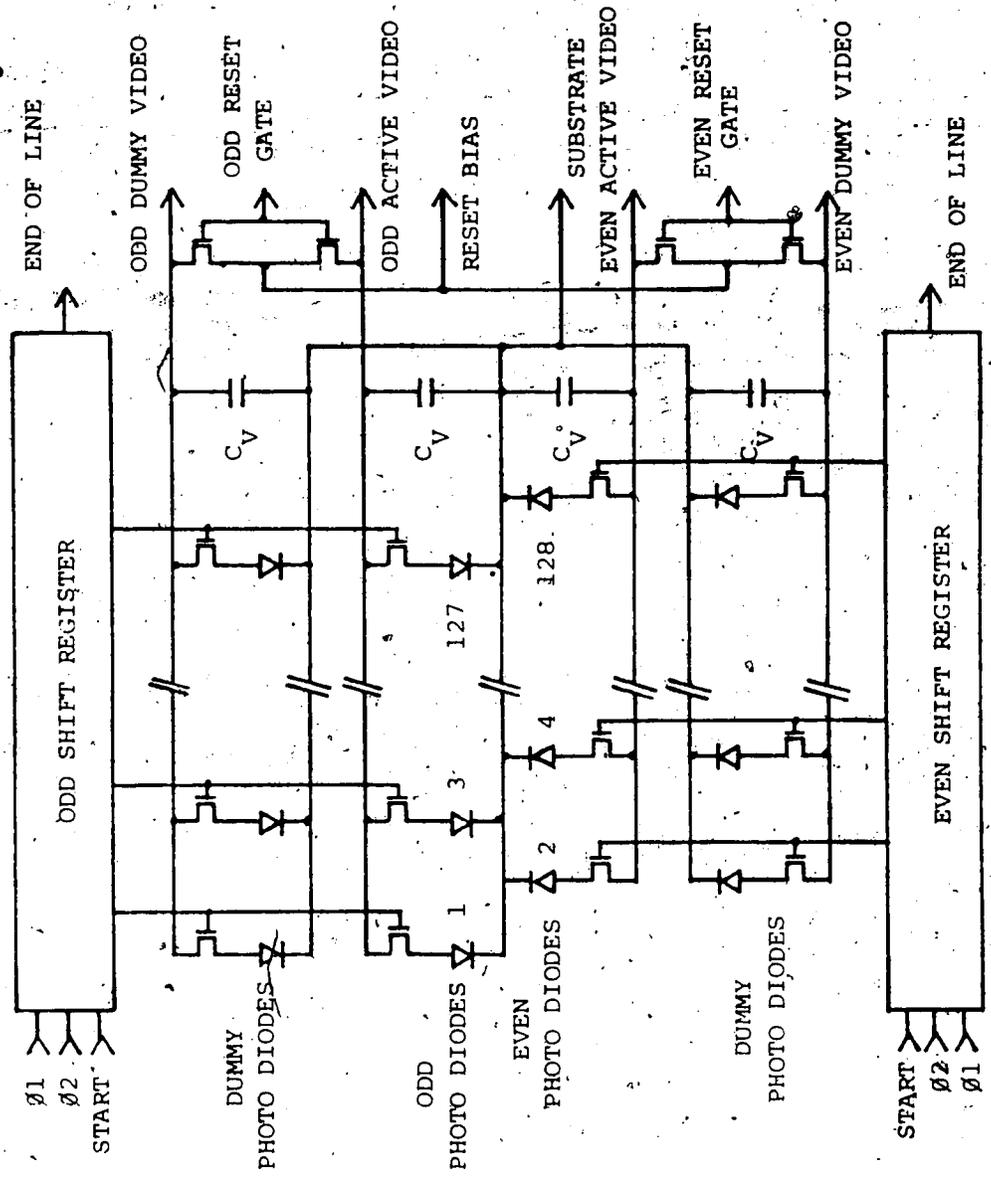


Figure 5. The equivalent circuit of the S series self scanning photodiode arrays [30].

video signal lines and the clock lines.

(i) In bulk silicon the density of thermally induced hole-electron pairs is given by [25]

$$n_T = 3.88 \times 10^{16} T^{3/2} \exp(-7015/T) \text{ per cm}^3$$

where  $T$  is the absolute temperature (K). The  $T^{3/2}$  term covers the change with temperature of the density of allowable electron states in the conduction band of the semiconductor. It has little effect on the temperature dependency of the hole-electron pair production unless the array is operated at temperatures below  $-60^\circ\text{C}$  [26].

At temperatures close to ambient, the exponential term is very significant. In practical terms, the dark current is halved for a  $7^\circ\text{C}$  drop in the operating temperature of the array. This is shown in Figure 6 [30].

In changing from photomultiplier tubes to photodiode arrays, the major loss is the approximately  $10^6$  times signal gain of the former. To partially compensate for this, the integration times of the photodiode arrays must be extended. In order to allow this, the signal due to the integrated dark current has to be reduced by cooling to prevent it from prematurely saturating the array.

(ii) The cross-coupling between the video signal and the various clock signal lines to the array is quoted in

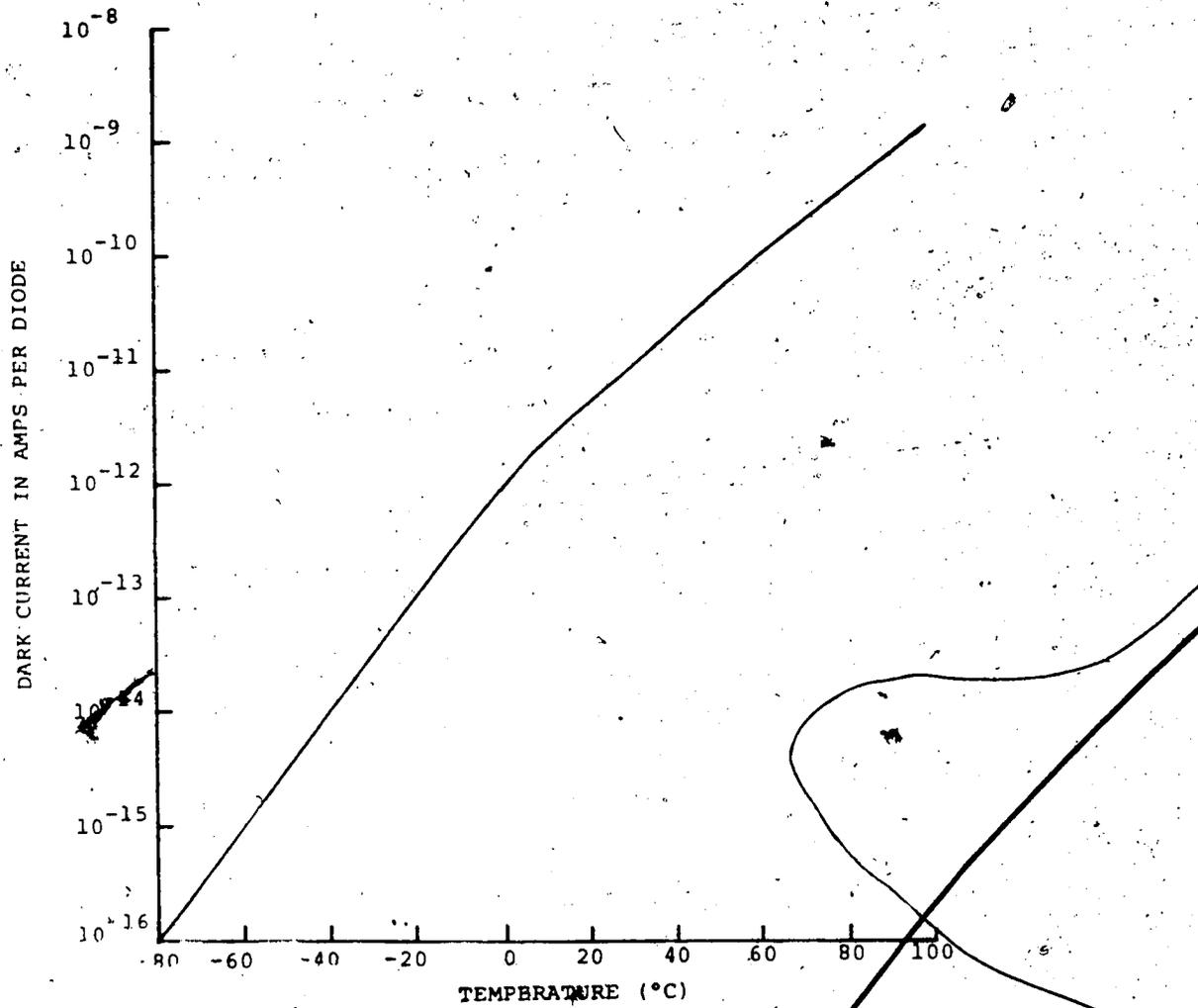


Figure 6. The temperature dependence of dark current [30].

the literature [23] as being of the order of 1% of the full-scale range of the diode array. Due to the physical restrictions placed on our system, this cross-coupling became a major factor that had to be controlled.

### 3.6 The RC1024S Printed Circuit Drive Board

The photodiode array is driven and its output processed by this circuit board which supplies the array with the following functions:-

- i. Regulation and control of input drive voltages.
- ii. An oscillator driven time base for the generation of all clock signals required for readout of the array and subsequent signal processing.
- iii. An extension of the same time base through logic counters to generate the start pulse for readout after the integration time has elapsed.
- iv. Synchronization of clock signal edges.
- v. Conversion of the TTL based clocking signals to TTL levels to drive the array shift registers.
- vi. Differential readout for active and dummy diodes for both odd and even sets of diodes.
- vii. Further signal processing including combining the odd and even readout signals into a single channel output signals.
- viii. Supply and control of a DC restoration level against diode dark current.

### 3.7 The Diode Array Mounting Carriage

The physical size of the RC1024S board (24 cm wide by 12 cm high) does not allow it to be considered as a direct carrier for the diode array in the focal plane of the direct reader. A carriage was built to carry the diode array in the focal plane. This clamps to the mounting rack that previously carried the exit slits (Photographs 1 and 2) where it can be moved to any position. (see Figure 7).

The array position on the carriage can be adjusted to and from the centre of the Rowland circle for focussing purposes and vertically to allow the array to be positioned for receipt of maximum spectral line intensity. ( It has rotational adjustment about an axis along the normal to the Rowland circle to align the diodes with the images of the entrance slit in the direct reader focal plane. The whole carriage is kept aligned so that the array is tangential to the Rowland circle, by two steel pins that are held in contact with the edge of the mounting rack.

In addition to the array, the carriage carries a cooling system that reduces the working temperature of the array and hence the dark current.

The RC1024S circuit board is mounted close to the carriage, on a metal plate clamped to the racks that

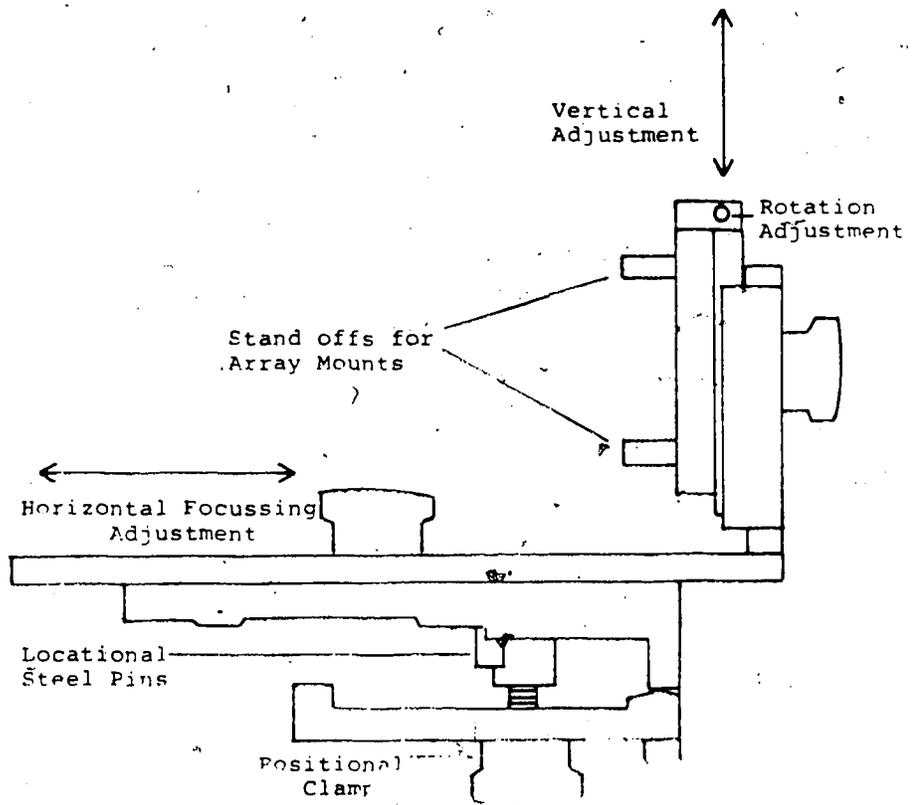


Figure 7. The diode array carriage.

originally were used to mount the photomultiplier tubes (Photographs 1 and 2). The array is connected electrically to the RC1024S drive board by a 22 wire ribbon cable, 37 cm long, soldered to a socket on the array carriage and to a plug that fits into the RC1024S board socket.

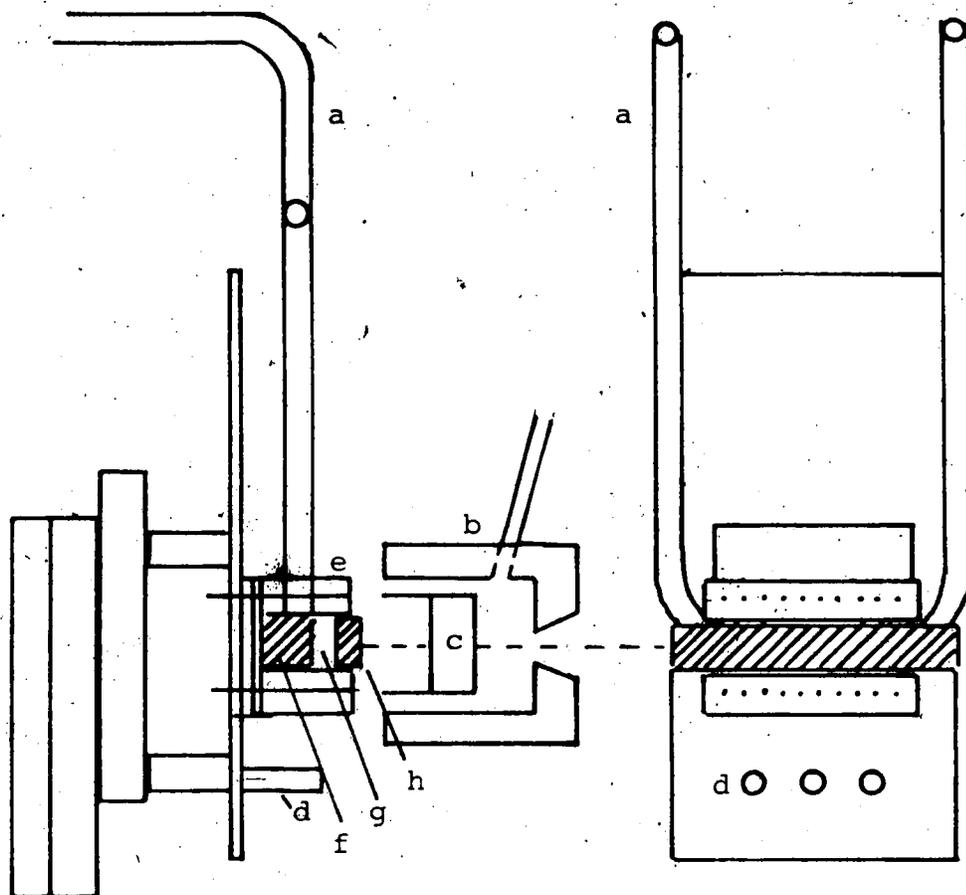
### 3.8 Cooling Systems

In order to reduce the dark current, the arrays are cooled using thermoelectric (Peltier effect) heat pumps.

Two types of coolers have been used.

(i) One, two or four miniature heat pumps, FC0.7-12-05L (MELCOR, Materials Electronic Products Corp., Trenton, NJ) are packed behind the array, between the two rows of electrical conductors in the 22 pin socket. The cold sides of the heat pumps are in contact with a copper bar that contacts the back of the array. The hot sides of the pumps are cooled by a water cooled copper heat sink (see Figure 8). Each of the miniature pumps is capable of transferring up to 1.56 watts.

(ii) A heat transfer bar is placed behind the array and connected to a copper plate mounted above the array. The copper plate is cooled by two CP1.4-71-06L Peltier effect heat pumps (MELCOR) which are themselves cooled by water cooled copper plates (see Figure 9). Each CP1.4-71-

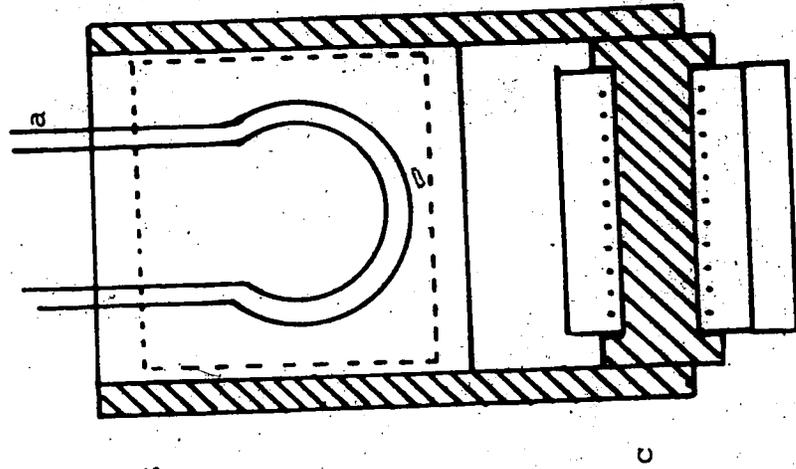


- a cooling water feed
- b mask to control dry  $N_2$
- c array
- d pins for attachment of heat pump wiring
- e socket
- f water cooled block
- g heat pumps
- h cooled copper block



FC 0.7-12-05L Heat Pump Actual Size

Figure 8. Array cooler based on miniature, Peltier effect, heat pumps.



a cooling water feed  
b heat pumps  
c cooled heat transfer system

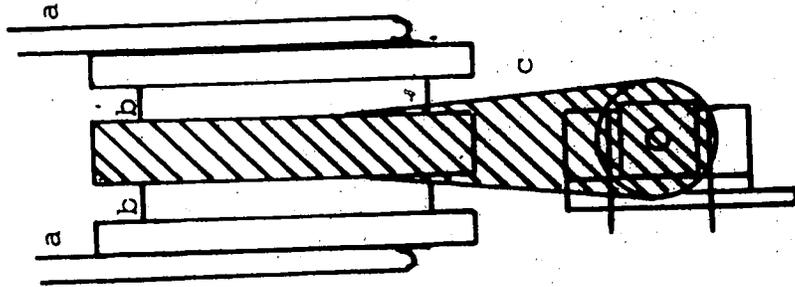


Figure 9. Array cooler based on larger, Peltier effect, heat pumps.

06L is capable of transferring 25 watts. These coolers can reach lower temperatures than the miniature pumps but they have to be carefully insulated to avoid water condensation and hence water saturation of the array socket.

All heat transfer surfaces are coated with a thin film of heat transfer paste supplied with the heat pumps.

A stream of low pressure (8-15 cm of water head) dry nitrogen is passed over the active portion of the cooled array to prevent the formation of an ice layer. The volume of nitrogen used is kept to a minimum by covering the array with a plastic mask that has a hole opposite the sensor portion of the array. These masks are made of black Delrin and partially shield the array against stray light.

#### 4. Data Handling Systems

The following four data handling systems were used at various stages of this project:-

- i. A transient recorder previously designed and built in our laboratory [33]. This had the capability of subtracting a recorded background from a signal. It could record a signal at a high sample rate (44 kHz) and later transfer that signal to an oscilloscope,

effectively converting it into a storage oscilloscope.

The clocking rate of the recorder could then be reduced so that the data were fed out at a rate to match the pen response speed of a chart recorder.

- ii. A PDP-8e minicomputer (Digital Electronics Corporation, Maynard, Mass.) fitted with a commercial 12 bit analog to digital converter. It was used at a sampling rate of 44 kHz. Like the transient recorder, it could subtract a recorded background from a signal and could support an oscilloscope and a chart recorder as outputs. It had the additional advantage of supplying data values in a printed form.
- iii. An AIM 65 single board microcomputer (Rockwell International Corporation, Anaheim, California) interfaced with an ADC 1131J (Analog Devices, Norwood, Mass.) high speed 14 bit analog to digital converter. This was run at a sampling rate of 10 kHz.
- iv. An Apple II+ microcomputer (Apple Computer Inc., Cupertino, California), interfaced with an AI13, 12 bit, 16 channel analog input system (Interactive Structures, Incorporated, Bala Cynwyd, Pennsylvania).

Both the AIM 65 and Apple based data processing systems were developed as part of this project and are described in more detail in Chapters IV and V.

## CHAPTER III

### PRELIMINARY EXPERIMENTATION

The RC1024S printed circuit boards, as supplied, would not drive the photodiode arrays in a manner suitable for use in a direct reader. Considerable modifications had to be made. This chapter describes why the modifications were necessary and how they were made.

#### 1. Modification of the Oscillator

A photodiode does not have the high gain capability of a photomultiplier tube and its response has to be integrated over an extended time period in order to record low levels of light intensity.

All timing signals on the RC1024S board derive from an oscillator which had a frequency adjustable from 150 kHz to 1.5 MHz. The readout process at the end of the integration period is initiated by a start pulse. The timing chain for the generation of the start pulses consisted of four 4 bit, presettable binary counters in series. This gave a maximum of 65,536 counts before overflow corresponding to an integration time of 0.437 s

when used to count a 150 kHz frequency. This was much too short for the direct reader. Additionally, during the readout process, diodes are sampled at every fourth cycle of the oscillator. This gave a minimum sampling rate of 37.5 kHz which is too fast for some data acquisition systems.

The oscillator is made from a Fairchild 9602 dual, retriggerable monostable multivibrator (see Figure 10). One monostable (B) runs as a fixed width pulse generator to give an output pulse width of approximately 100 ns. The other monostable (A) is used to generate the major portion of the oscillator period and its pulse width is controlled by a variable resistance.

The pulse width (time at high logic level) of the monostable is given by [34]

$$t_w = 0.31 C_x R_x \left(1 + \frac{1}{R_x}\right)$$

where  $t_w$  is in ns,  $R_x$  in  $k\Omega$  and  $C_x$  in pF.

The pulse width range of the variable monostable (A), where  $R_x = R_2 + R_1$  (variable) and  $C_x = C_1$ , was altered by changing the capacitor  $C_1$  from 500 pF to 0.005  $\mu$ F. This changed the controllable frequency range of the oscillator to 16-260 kHz and the corresponding sampling rate to 4-62.5 kHz.

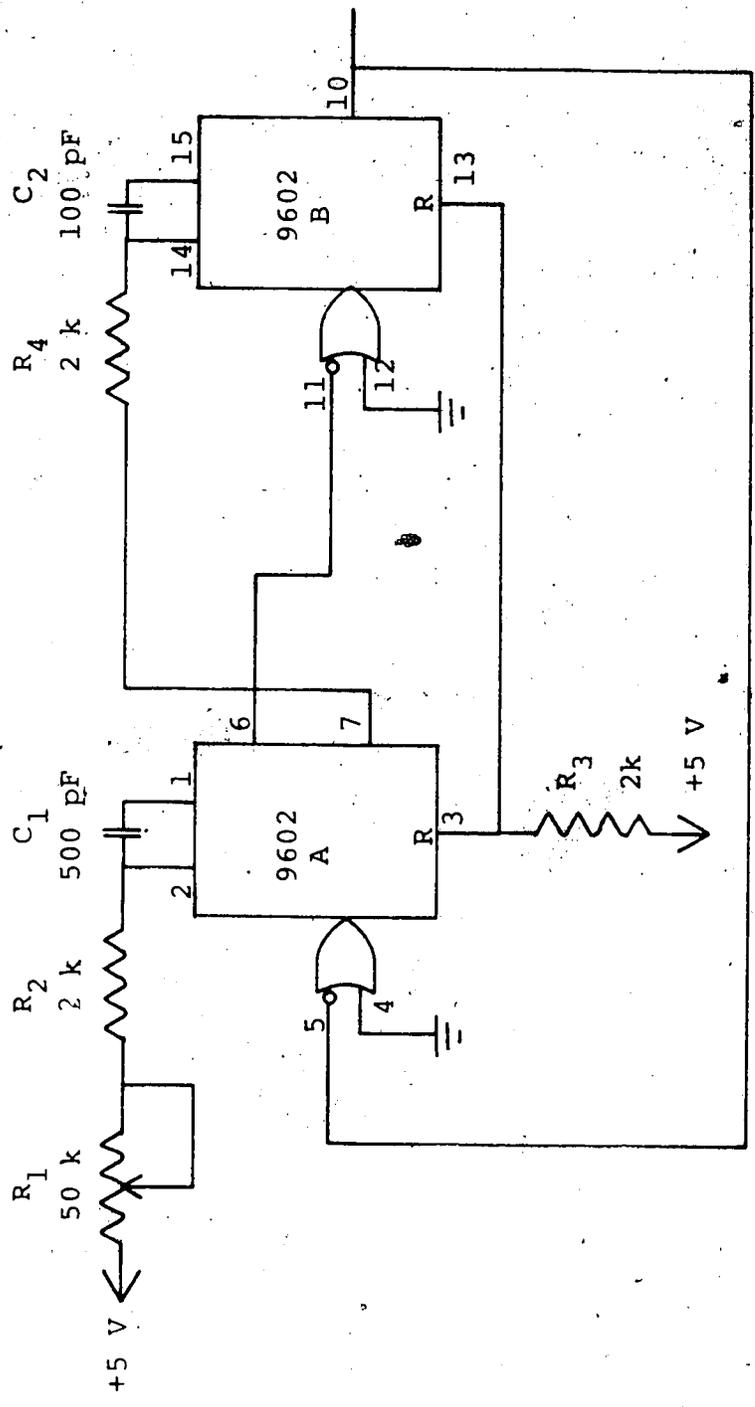


Figure 10. The timing oscillator.

## 2. Extension of the Integration Timer

The oscillator modification suited the sampling rate but left the integration times still too short. This problem was corrected by increasing the timing chain from four to six 4-bit binary counters.

The last counter on the RC1024S board was removed and replaced by a DIP socket. Three more counters were mounted on a separate circuit board and connected to the RC1024S board by a plug-in ribbon connector (see Figure 11). This board was mounted parallel to and behind the RC1024S board. The three remaining counters on the RC1024S were set to full count. The counters on the extension board were connected through a ribbon cable to twelve switches mounted outside the dark box of the direct reader. The value of a bit on the extra counters could be added into the count by grounding its input control line with the corresponding switch. When the bit was not required in the count it was held at logic high by connecting to the 15 V supply through a 2.2 k $\Omega$  resistor.

The six 4 bit counters gave a maximum of  $16.78 \times 10^6$  counts before overflow and, coupled with an oscillator set to give a 40 kHz sampling rate, allowed for integration times of up to 105 s.

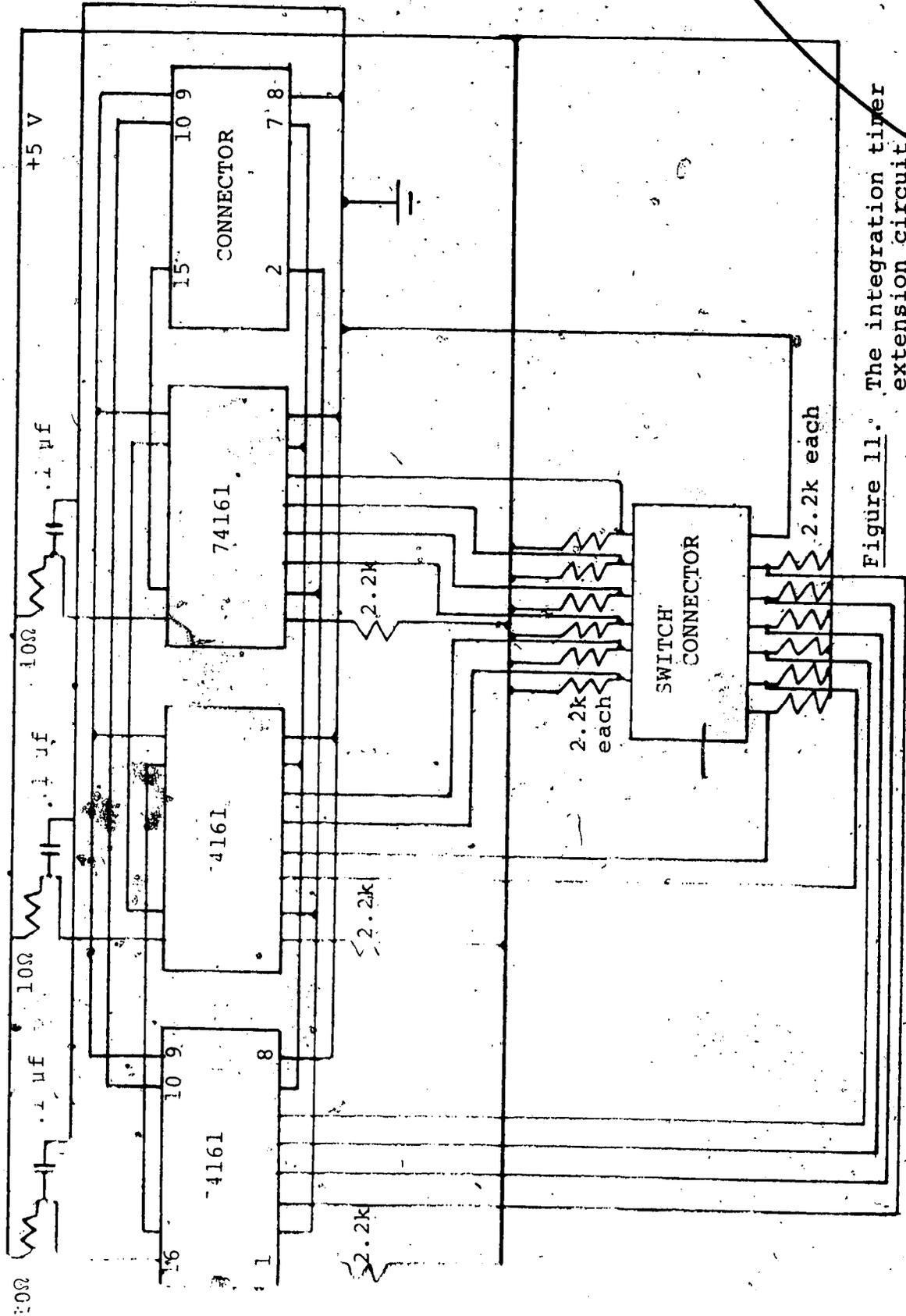


Figure 11. The integration timer extension circuit.

### 3. A Data Acquisition Control Signal

A data acquisition system requires a control signal or trigger to initiate the collection and processing of a data value. The RC1024S board generates separate trains of sampling pulses for the odd and even series of diodes. At one point on the circuit board these are logically OR'd into one. This OR'd pulse train was picked up and connected to a spare edge connector tab on the circuit board. The widths of the pulses in this train were dependent on the frequency of the oscillator. This had to be changed so that the pulse width could be matched to the requirements of a subsequent data acquisition system.

It was also necessary to delay the data acquisition pulse so that the signal could be acquired when the signal output from the individual diodes was steady. The PC1024S circuit uses a differential readout of active and dummy diodes to minimize switching transients as the diodes are coupled, in turn, into the video output line. This is not so effective when the diode array is running directly from the PC1024S board and switching is done directly in the output signal.

A high speed data acquisition system contains an analog to digital converter. During the conversion the analog signal is held constant by a sample and hold amplifier. When the sample and hold amplifier is not tracking

the analog signal to hold, there is a small uncertainty in the time aperture during which the switching occurs.

(Typically 0.5 to 1 ns with a fast acting device [35].)

For accurate sampling, it is important that the signal to be converted does not change significantly during the switch to hold. Thus the analog signal from each diode must be sampled after the switching spike has passed.

Additionally, the signal may be preamplified both to take advantage of the full input range of the analog to digital converter and to have high frequency noise removed with a low pass filter. The damping effect of an amplifier will act on any sharp transitions in the analog signal (such as switching spikes) and further prolong their effect. For example, an array was sampled at 50 kHz or 20  $\mu$ s per diode. Of this 20  $\mu$ s, 5  $\mu$ s was taken by the switching spike and a further 400 ns taken by the decay from the spike. A simple times three amplifier based on two CA3140 operational amplifiers caused the decay time from the spike to increase to 2  $\mu$ s giving a total of 7  $\mu$ s of disturbance in the 20  $\mu$ s signal.

The data acquisition pulses were both delayed and their active widths made independent of the oscillator by the circuit, given in Figure 12, based on two 74121 monostable devices. The output of the delay monostable (A) goes to logic high on receipt of a negative transition

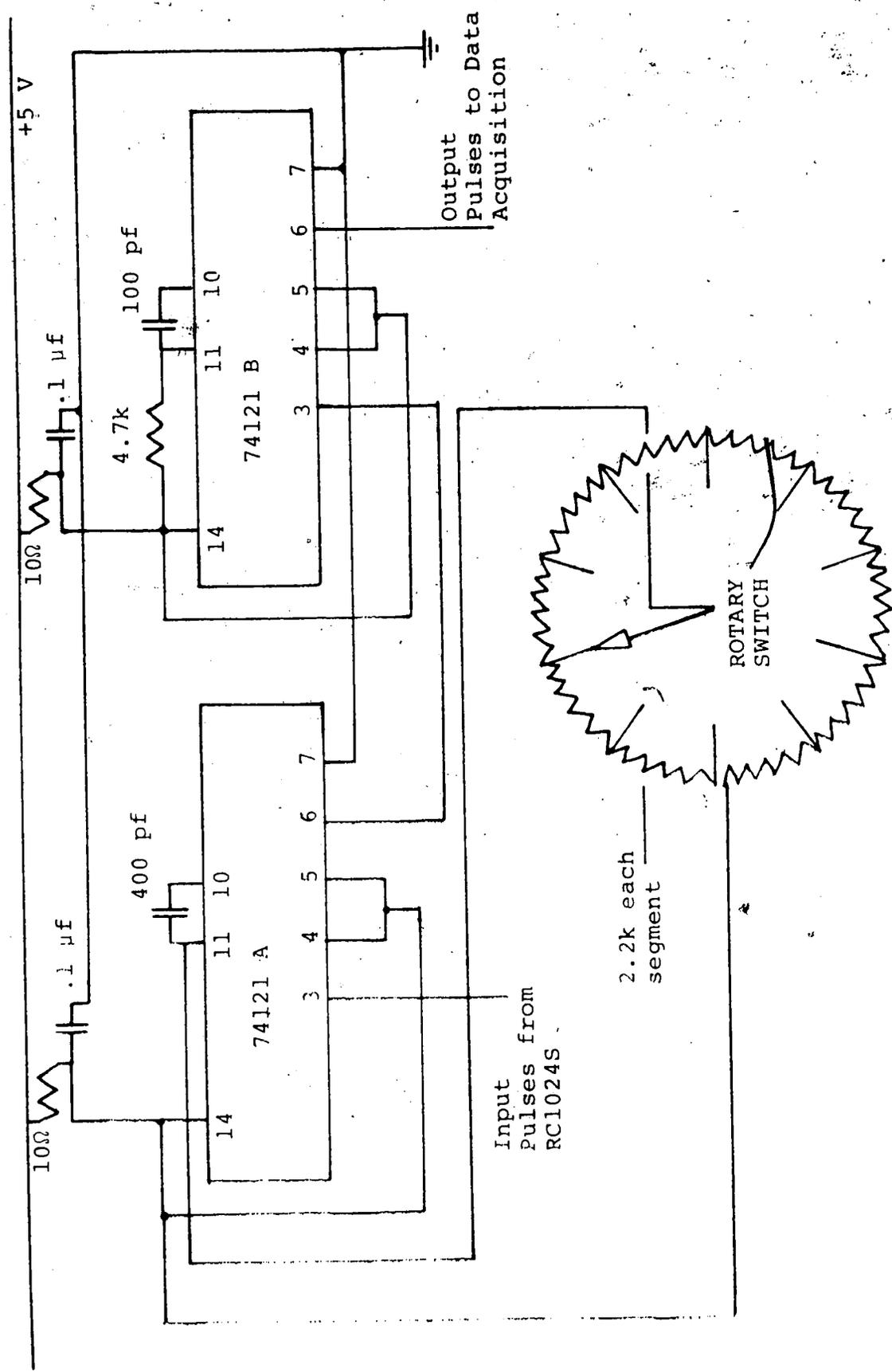


Figure 12. The data acquisition control signal circuit.

from the RC1024S board. Its pulse width is controlled by the value of the timing capacitor (400 pF) and the switched-in timing resistors.

At the end of the controlled pulse width, the output goes low and triggers the start of the high level pulse on the pulse width control monostable (B). The output of the second monostable is used to signal the data acquisition system. The circuit shown in Figure 12 delayed the pulse from 5 to 10  $\mu$ s and gave a pulse width of 400 ns. This version used a bank of fixed value resistors and a rotary switch to get repeatable delays for test purposes. Subsequent versions of this circuit used miniature trimming resistors on both monostables to give fine control of both the delay and pulse widths.

#### 4. Signal Reduction Due to Extension

With the photodiode array plugged directly into the RC1024S circuit board, the signal from a fully saturated diode was approximately 3 volts. When mounted on the carriage away from the board, the signal value was only 1 volt.

This was investigated and it was found that separating the diode array from the circuit board by very small distances affected the signal value. Spare sockets were interposed between the array and the board and it was

found that 8 sockets corresponding to a stand off distance of 4 cm reduced the signal by 20%.

When using the extension, the ribbon cable, socket and plug are between the array and its first amplifier stage (the differential amplifier). The readout mechanism for the photodiodes involves the sharing of charge between the diode and the video line. 28AWG ribbon cable has a capacity per line of 17.5 pF for a 38 cm length; well in excess of the 2 pF capacitance of each photodiode and the 3 pF capacitance of the array video line. Consequently the input voltage at the first amplifier stage is much reduced and this reduction continues through all subsequent amplifier stages.

Although the signal is reduced, it is still at an acceptable level and can be readily processed through external operational amplifiers to suit a data acquisition system.

##### 5. Rapid Saturation of the Photodiodes

When a photodiode array was operated in extension, away from the board, it rapidly saturated with dark fixed pattern signal. This is illustrated in Figure 13 for the room temperature measurement of the 632.8 nm output of a helium-neon laser (highly filtered). The background increased rapidly, especially on the left side of the

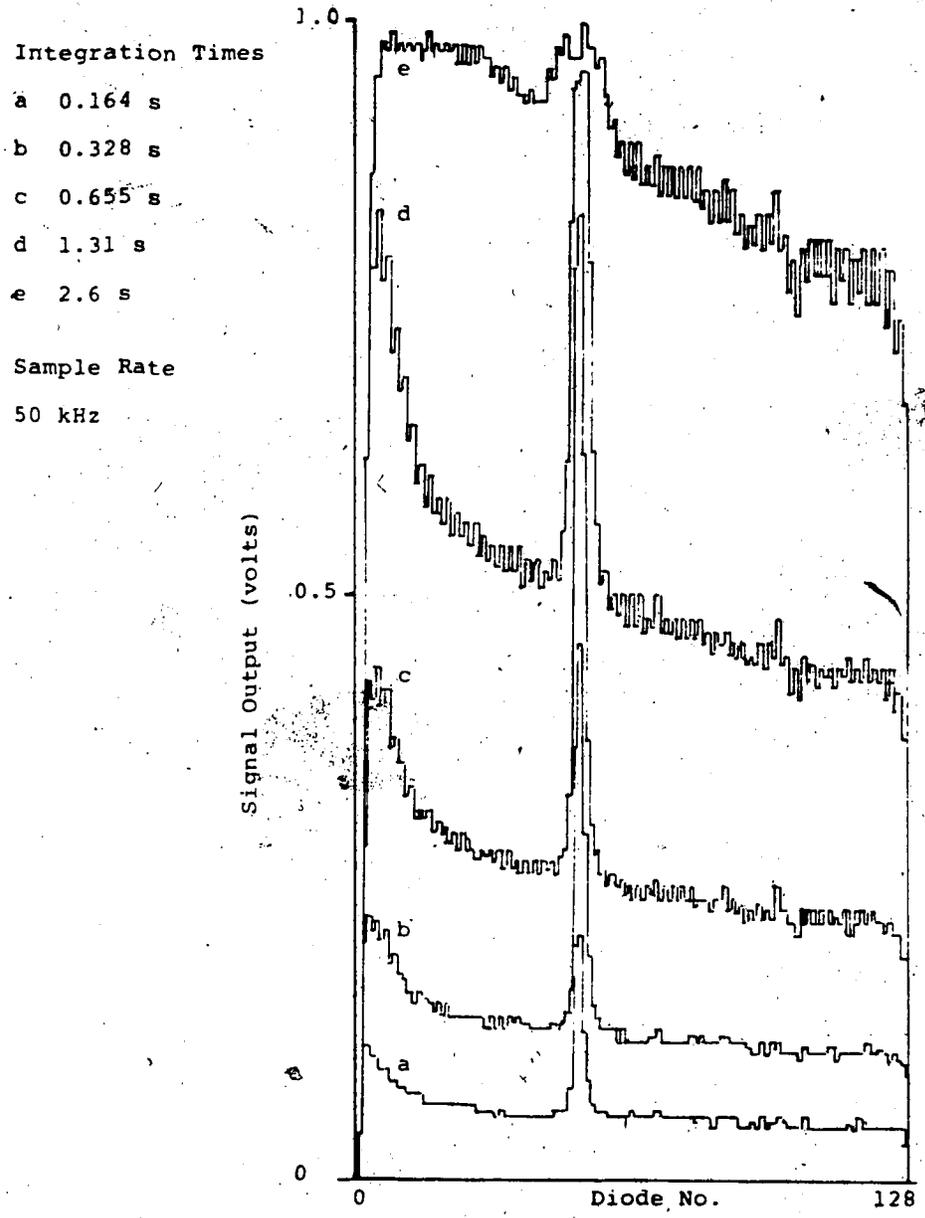


Figure 13. The rapid saturation of a diode array.

array where saturation started to occur at 1.6 s. The whole array would have been saturated by background in 3.2 s. This did not occur when the array was plugged directly into the RC1024S circuit board.

A cooling system (Figure 8) based on 2 miniature Peltier effect heat pumps was fitted to the array in extension. With a sampling rate of 43.5 kHz and 0.9 s integration time the effect of the cooler on this background signal was found to be minimal. It dropped the background level about 2% on the left side of the array and about 20% on the right side of the array. Because the efficacy of the miniature Peltier coolers was in doubt, the more powerful cooling system (Figure 9) was used. Again the background dropped very little on the left side of the array and by only about 50% on the right side. As the temperature of the array was measured as  $-27^{\circ}\text{C}$ , a drop of  $47^{\circ}\text{C}$  below the temperature of the room, it was obvious that the background was not thermal in origin.

## 6. Investigation of the Background Effect

The internal temperature of the diode array integrated circuit was estimated by taking the mean of the temperature measured by two thermocouples, one in front of the array, the other between the array and the cold bar of the cooler. The difference between these 2 measurements

was a maximum of 7°C at the extremes of the temperature ranges measured. The array temperature was varied over the range 261 to 340 K (-22 to 67°C) by controlling the voltage applied to the heat pumps. Temperatures above ambient were obtained by reversing the voltage across the pumps and so driving them, in reverse. The array output signal was preamplified to give 10 volts at saturation.

For each array temperature, the output signal was measured for the left and right sides of the array for several integration times. The natural logarithms of the values were plotted against temperature for 2 integration times (Figure 14).

A similar plot developed from the formula for thermally induced hole-electron pairs [26]

$$n_T = 3.88 (10^{16}) T^{3/2} \exp(-7015/T) \text{ per cm}^3$$

would be almost linear but deviating towards the abscissa at lower temperatures. None of the curves on Figure 14 corresponded to this. The nearest was for the right side of the array at the lower integration time. The curves were interpreted as follows.

The background signal contained at least 2 components. One was the temperature and time dependent result of the generation of hole-electron pairs. The

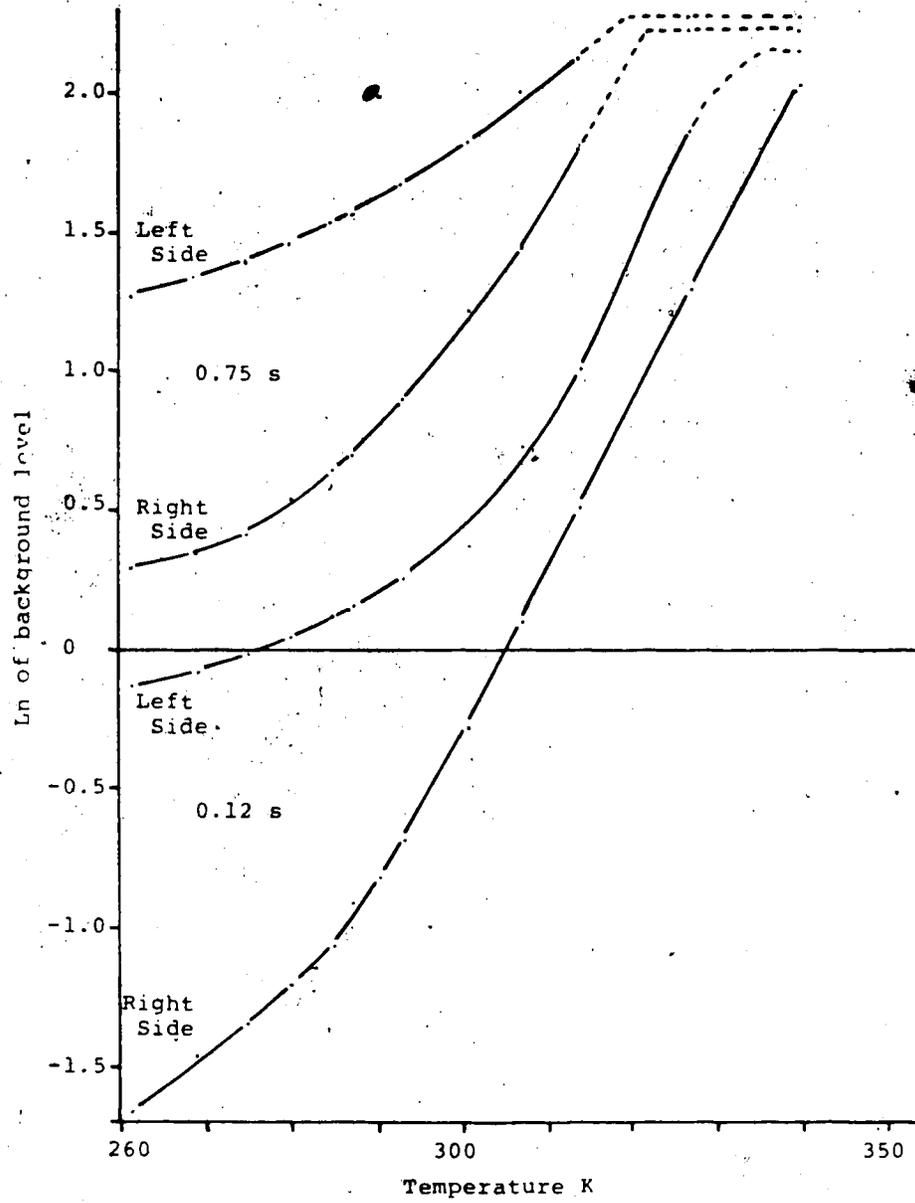


Figure 14. Variation of background signal with temperature for 2 integration times.

other was a time dependent but probably temperature independent background signal which was stronger on the left side of the array than on the right.

Because it diminished across the array, the time dependent, temperature independent background must have been either a function of distance from some fixed spot in the array or a function of time during the readout process taking the start pulse as the time origin.

The integration time was the product of the oscillator period and the count preset on the timing chain.

The oscillator frequency was changed and the counter setting altered to compensate and maintain the same integration times. The effect of making such changes on the background level on the right side of the array at room temperature are shown in Table 1. This shows that there was some dependence of background on the sampling rate. This was further investigated by cooling the array to  $-27^{\circ}\text{C}$ . At these relatively short integration times, the time integrated dark current at  $-27^{\circ}\text{C}$  should be insignificant so that background would be due to the temperature independent effect (Table 2).

Comparison of Table 2 with Table 1 shows that the background levels were reduced by reducing the thermal dark current and there was a direct relationship appearing

Table 1. Effect of changing sampling rate on background level at room temperature.

Sampling Frequency = $\frac{\text{Oscillator}}{4}$	Signal (Volts. 10 = Saturated) at integrations of				
	0.0942 s	0.1884 s	0.377 s	0.754 s	1.51 s
87 kHz	0.5	1.15	2.4	4.85	-
43.5 kHz	0.27	0.68	1.45	2.95	-
21.7 kHz	0.17	0.4	0.90	1.9	3.7
10.9 kHz	-	0.2	0.66	1.45	3.0

Table 2. Effect of changing sampling rate on background level at  $-27^{\circ}\text{C}$ .

Sampling Frequency = $\frac{\text{Oscillator}}{4}$	Signal (Volts. 10 = Saturated) at integrations of				
	<del>0.0942 s</del>	0.1884 s	0.377 s	0.754 s	1.51 s
43.5 kHz	0.07	0.22	0.55	1.3	2.5
21.7 kHz	0.03	0.08	0.26	0.6	1.2
10.9 kHz	-	0.03	0.06	0.2	0.4

between sampling rate (or the oscillator frequency) and the background level. These results together with others are rearranged in Table 3.

Thus the temperature independent background was linearly related to the number of oscillator periods in the integration time.

#### 7. Removal of the Background Effect

The oscillator, through the first 4 bit counter of the counter chain and a read only memory (ROM) integrated circuit, sent 6 pulse trains continuously to the array.

It was not known which of these pulse trains was responsible for the background problem but with the array in extension there was considerable crosstalk between the signals in the wires that make up the ribbon cable. For example, the start pulse line picked up a 0.35 V induced pulse every 16 oscillator pulses continuously over the full length of the integration time.

Although the pulse trains were sent continuously, they were only utilized by the array during the readout process, after a start pulse had been generated. The reason that they were sent continuously is that the same oscillator drove both the readout mechanism of the array and the integration timer chain (see Figure 15).

Table 3. Relationship between background level and the number of sample pulses per integration at  $-27^{\circ}\text{C}$ .

Signal (Volts) and Integration Times (s) and Sampling Pulse Counts								
	16,384 Counts		32,768 Counts		65,536 Counts		131,072 Counts	
kHz	SIG (V)	INT (s)	SIG (V)	INT (s)	SIG (V)	INT (s)	SIG (V)	INT (s)
43.5	0.55	.377	1.3	.753	2.5	1.51	5.4	3.01
21.75	0.6	.753	1.2	1.51	2.6	3.01	5.2	6.03
10.9	0.4	1.51	1.2	3.01	2.5	6.03	6.4	12.1

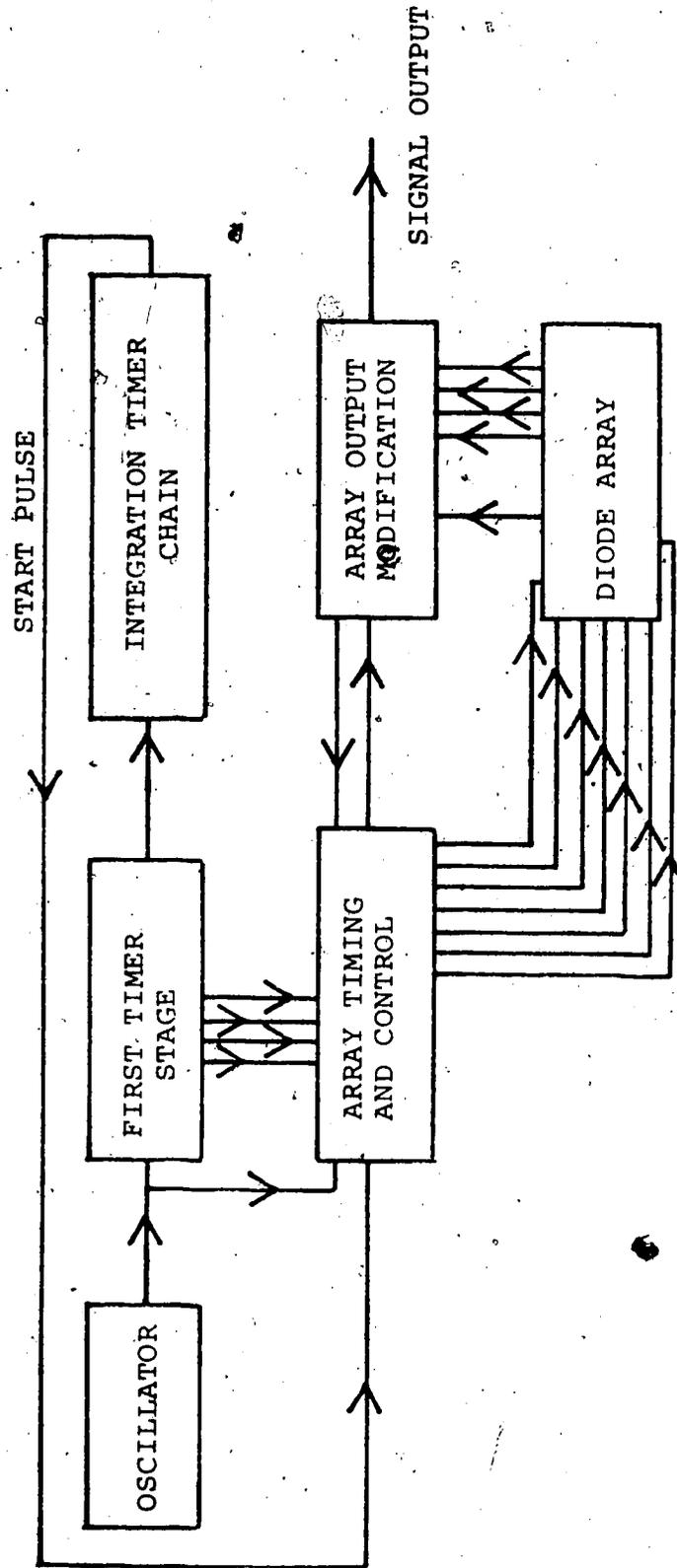


Figure 15. Schematic diagram of the RC1024 S array control system.

The alternative method of driving the array that solved the background problem is shown in Figure 16. The integration time is controlled by generating a start pulse away from the RC1024S circuit board. The oscillator is connected to the first timer stage, not directly, but through a logic gate. Although the oscillator runs continuously, it does not drive the system and hence send pulses to the array until the logic gate opens. The rising edge of the externally generated start pulse opens the gate and connects the oscillator to the timing chain and the array controls. The timing chain no longer controls the integration time but it is used to control the open time of the gate.

The timing chain is preset to allow 132 sample pulses to be generated and then its overflow pulse triggers the gate control to close the gate, after readout has been completed, and so re-isolate the oscillator from the rest of the circuit. Thus, regardless of the length of the integration time, the array receives only those pulses necessary for proper readout and is pulse free and consequently crosstalk free for the rest of the integration period. The timing sequence at the start of the readout cycle is shown in Figure 17. The externally generated start pulse goes high and opens the gate. At the same time it sends the output of a 7474 flip-flop on

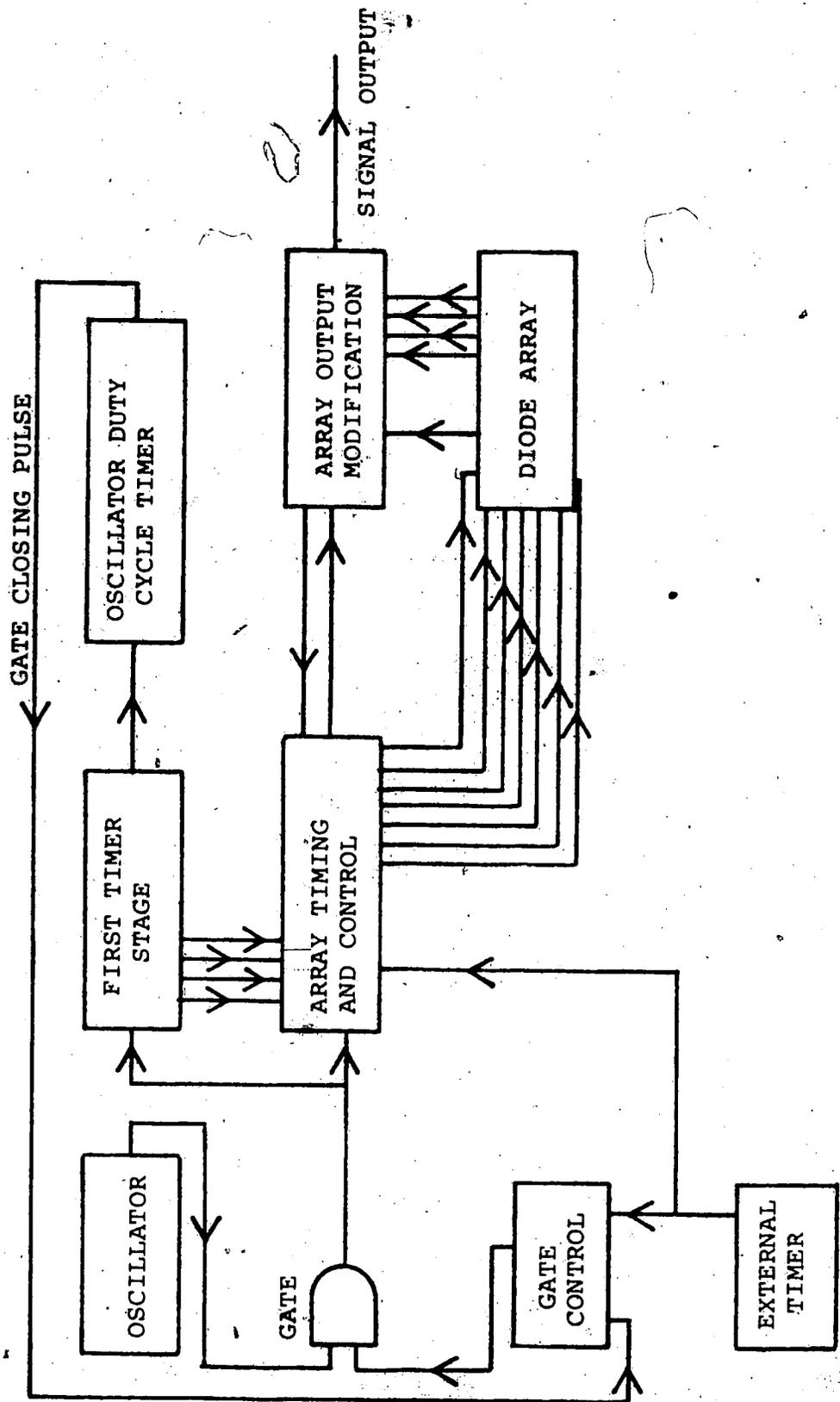
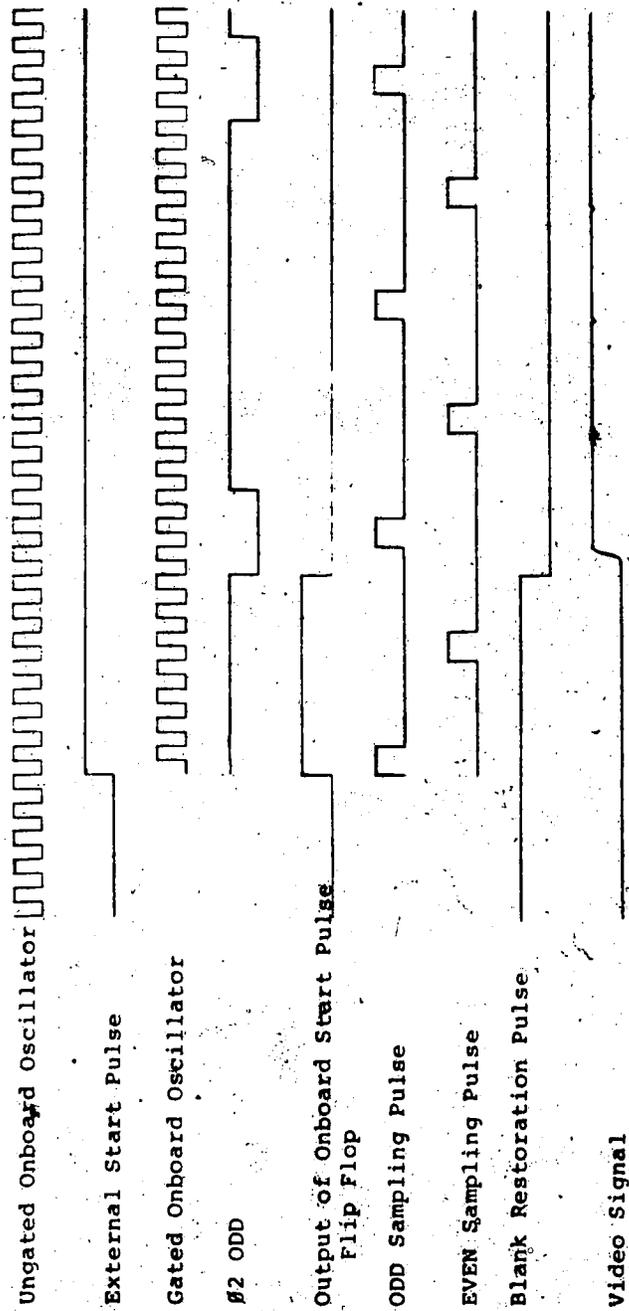


Figure 16. Schematic diagram of the gated array control system.



**Figure 17.** Timing diagram for the start of readout.

the RC1024S board high (see Figure 18). The oscillator is now connected to the control system which starts to generate its trains of timing pulses. As soon as one of them, called Ø2 ODD, goes low for the first time, it clears the onboard 7474 flip-flop (Figure 18), sending its output low. It is this high to low transition, inverted and converted to MOS logic levels by the MH0026, that acts as the true start pulse for the array. At the same time the complementary output of the 7474 flip-flop goes high and clocks a second 7474 flip-flop which, in turn, cuts off the blank restorative signal. The blank restorative signal is that signal that the board puts out when the array is not being read out.

The photodiode signal values are then processed by the RC1024S circuit board under the control of the sampling pulses. During the time that the start pulse 7474 flip-flop is high, two sampling pulses are generated. The software of the data handling system must be designed to ignore these first two pulses as they occur before the photodiode array readout has started. This is done by waiting for the negative edge of the flip-flop output to occur before taking data values.

The timing sequence at the end of readout is shown in Figure 19. As the last diode (number 128) is read out, the array sends out an end of line signal. This is fed to

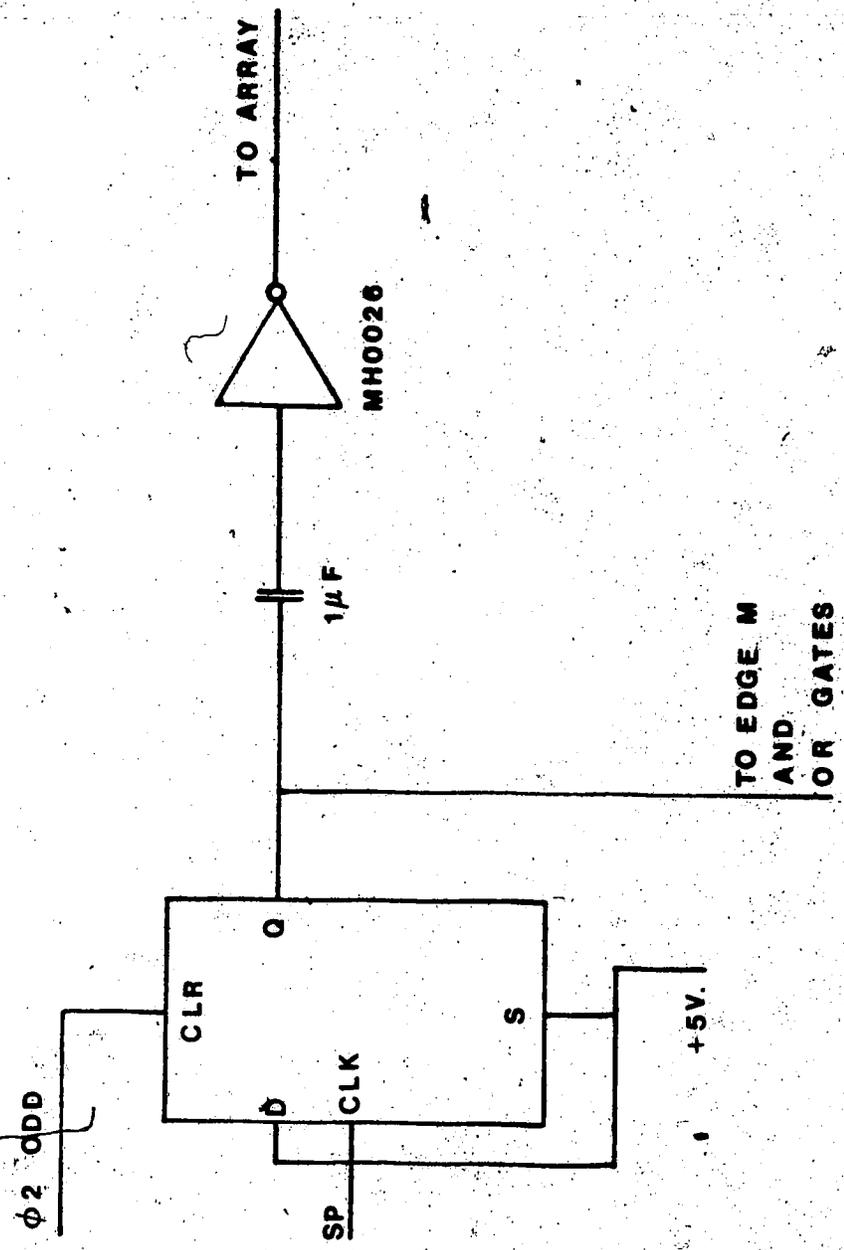


Figure 18. The start pulse circuit on the RC1024S board.

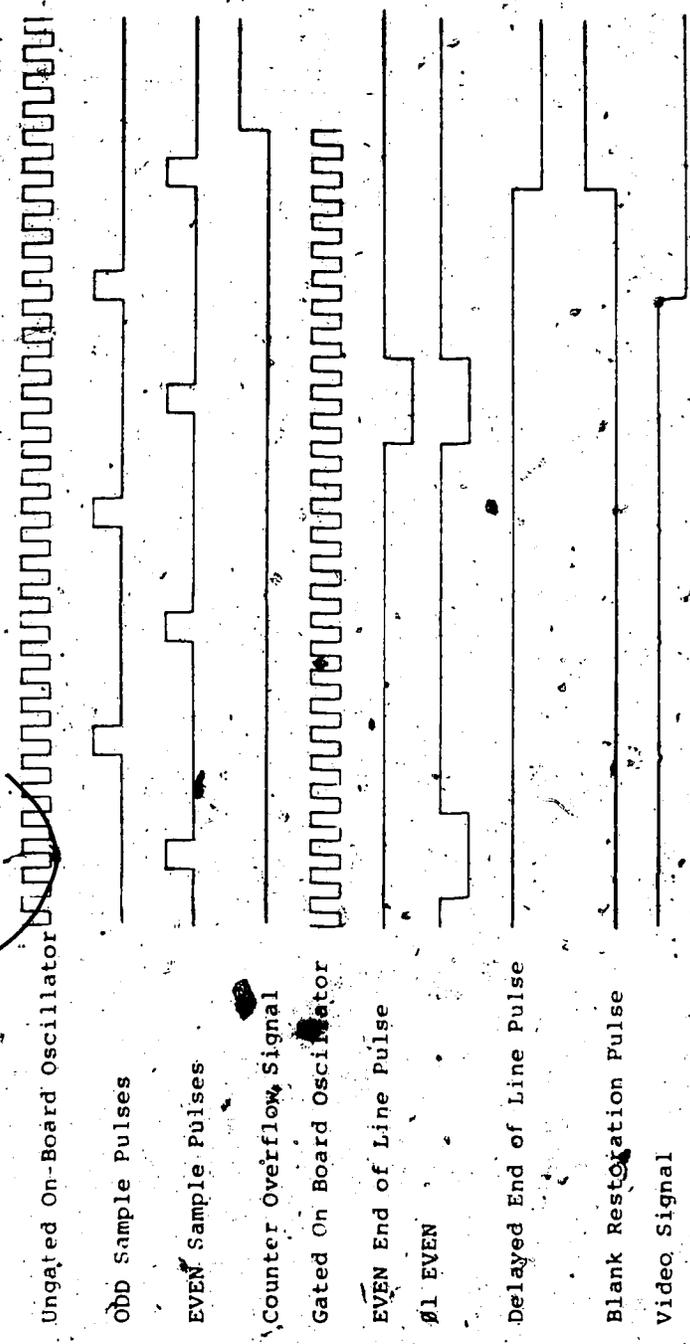
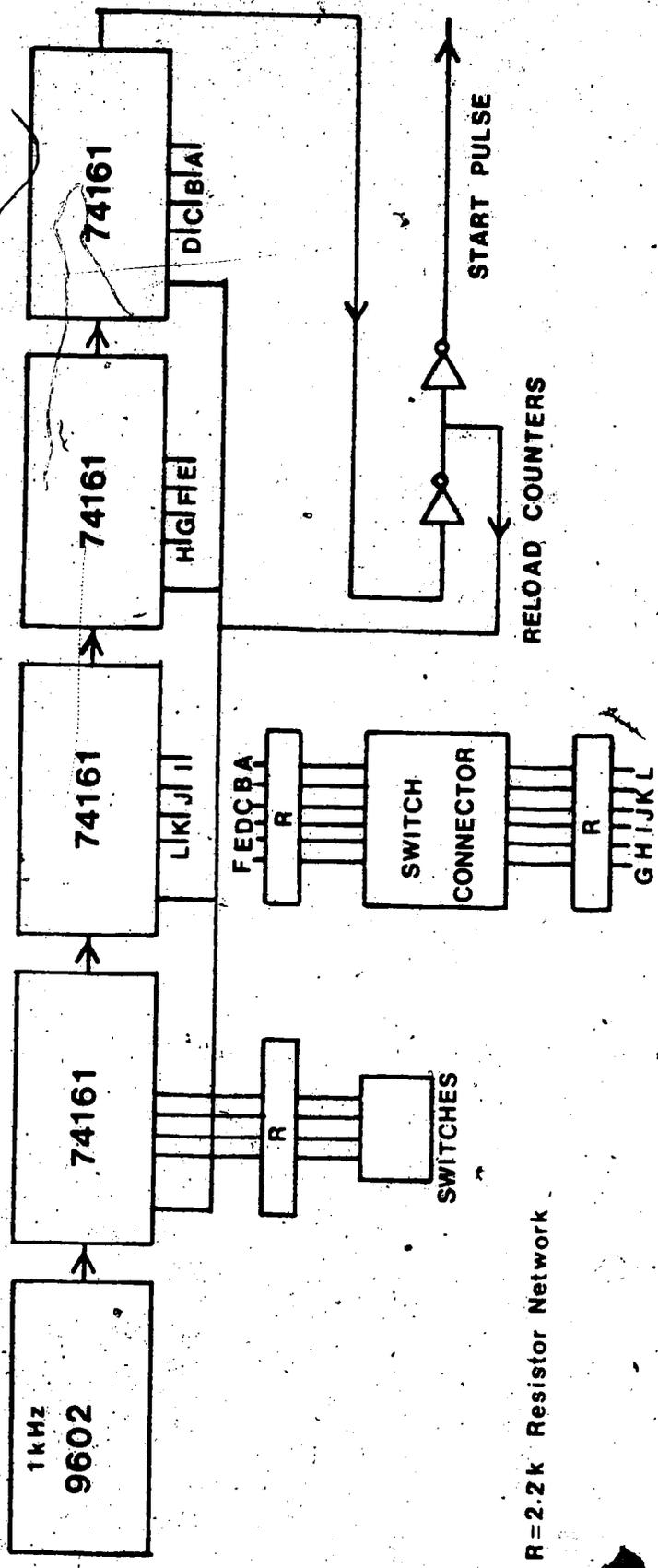


Figure 19. Timing diagram for the end of readout.

a shift register on the RC1024S board where it remains until the next even sample pulse is generated. This sample pulse clocks the shift register, and, now delayed, clears the 7474 flip-flop controlling the blank restorative level, thus restoring that level. This takes a further 2 sample pulses so at least 132 sample pulses have to be generated to read out the array.

The external start pulse generator is shown in Figure 20. It consisted of a 9602 dual monostable generating approximately a square wave at a frequency of 1 kHz. Four 4 bit counters 74161 were used as a timing chain. The controlling inputs for the first counter were switched to ground for it to have a full count of 16. The controlling inputs for the remaining 3 counters were held high by connecting them to the +5 V supply through 2.2k resistors, but they could be grounded through a ribbon cable using switches outside the dark box of the direct reader. The overflow pulse from the counter chain was inverted to give a pulse to enable the reloading of the counters and then reinverted to give the required start pulse. The oscillator was tuned slightly so that the external switches controlled the integration time over the range of 15.6 ms to 64 s.

The gate consists of a dual edge triggered D type flip-flop 7474 and a quad NAND gate 7400 (Figure 21). The



R = 2.2 k Resistor Network

Figure 20. The external start pulse generator.  
(This is the external timer in Figure 16.)

*[Handwritten scribble]*

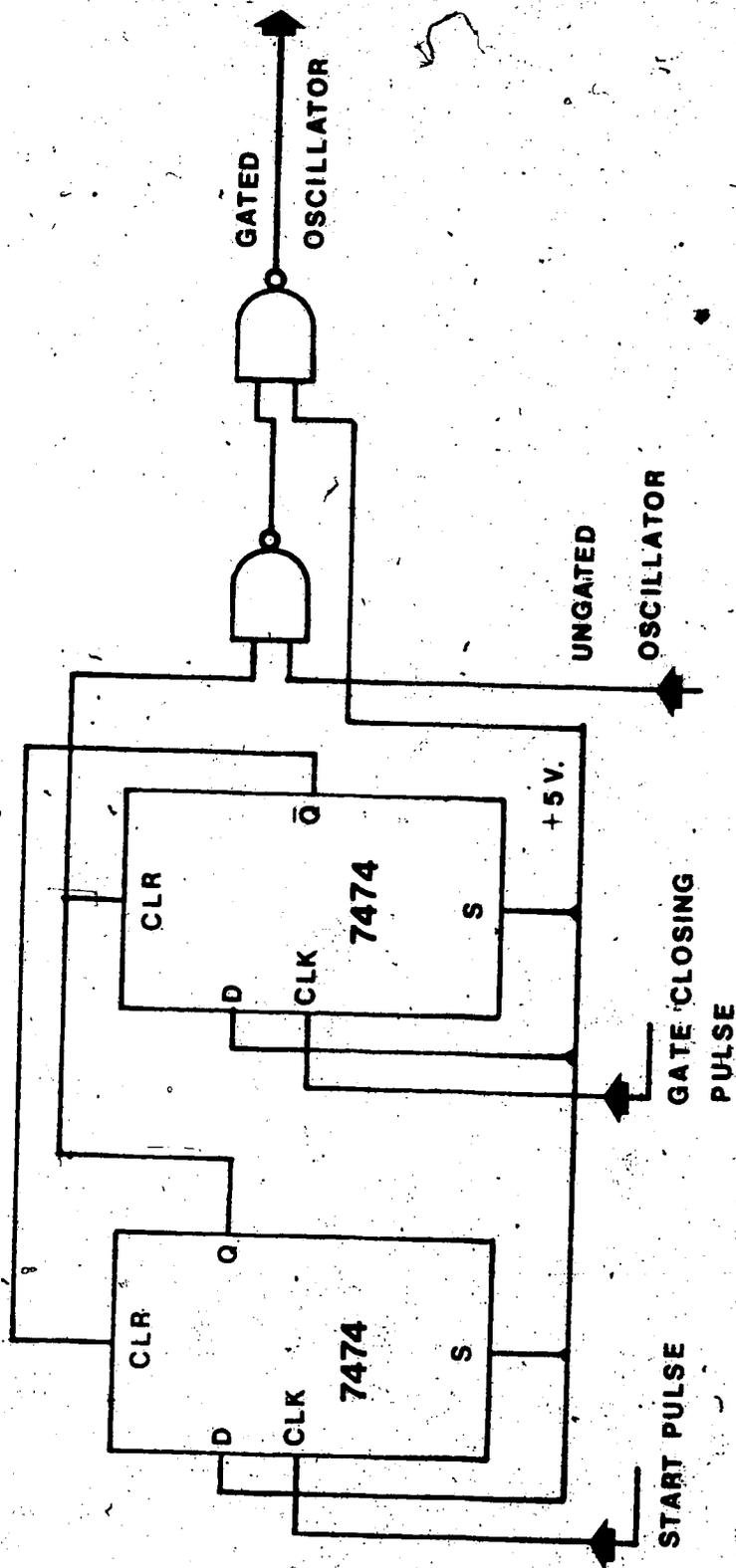


Figure 21. The oscillator gating circuit.

(This is the gate control and gate in Figure 16.)

D and S inputs of both flip-flops are locked high. In this mode the output of each flip-flop goes high on the first rising edge received at the clock input, whether the rising edge is the leading or trailing edge of a pulse.

The Q output of the first flip-flop is the gate control. It goes high and opens the gate when the flip-flop is clocked by the rising edge of the externally generated start pulse. When readout has been completed the overflow pulse from the RC1024S board clocks the second flip-flop sending its Q output high and its complementary  $\bar{Q}$  output low. This  $\bar{Q}$  output clears the first flip-flop which closes the gate and then clears the second flip-flop. The device is now ready for the next start pulse to occur.

The gate control level from the first 7474 flip-flop and the output of the oscillator from the RC1024S board are inputs to a 2-input NAND gate. When the gate control level is high the output from the NAND gate is the inverted oscillator signal. This is reinverted using a spare gate on the 7400 in the inverter mode.

The start pulse generator, the gate and the data acquisition control signal modification circuits were all mounted on a board attached behind the RC1024S board.

The alterations to the RC1024S board covered in this chapter are described in detail in Appendix 2.

Use of the gated oscillator method of running the array removed the temperature independent background problem. The integration time is now limited by the true dark current caused by the thermal generation of hole-electron pairs. This current did not saturate the photodiode array in 64 s (the limit of the integration timer system) at  $-2^{\circ}\text{C}$ .

## CHAPTER IV

### A SINGLE ARRAY SYSTEM AND THE AIM 65 MICROCOMPUTER

A single array system was built as a precursor to the multiple array direct reader in order to gain experience with operating conditions, software design and data evaluation.

It was based on the use of the gated oscillator and the externally generated start pulse method of running an array as described in Chapter III. A data acquisition system was assembled based on the Rockwell AIM 65 single board microcomputer and a high speed, successive approximation, analog-to-digital converter. The system was used to determine the operating characteristics of the array and its response as a quantitative spectrophotometric detector.

#### 1. Interfacing the Array to the Computer

The whole detector, data collection system involved the following components:-

- i. The photodiode array.
- ii. The array carriage and its ribbon cable.

- iii. The array drive board RC1024S.
- iv. The supplementary circuits to generate the start pulse, gate the oscillator and modify the data acquisition control pulses.
- v. An analog multiplexer and preamplifier.
- vi. An analog to digital converter complete with sample and hold amplifier.
- vii. The AIM 65 computer.

The first four components have been described in previous chapters.

#### 1.1 The Analog Multiplexer and Preamplifier

The circuit for this is drawn in Figure 22.

The HI-508A (Harris Corporation) is an eight channel CMOS analog multiplexer. Although not required in a single channel system, it was included because it, or a similar device, would be needed in a multiple array system. It was used here, permanently switched to input channel number 1 by grounding the input control lines.

The operational amplifiers used were TL081 (Texas Instruments), a high slew rate, JFET-input type. The first operational amplifier acted as a second order low pass filter (40 dB fall off per decade) with an adjustable 3 dB point in the 5-50 kHz range. The design came straight from a manufacturers handbook [36]. It also

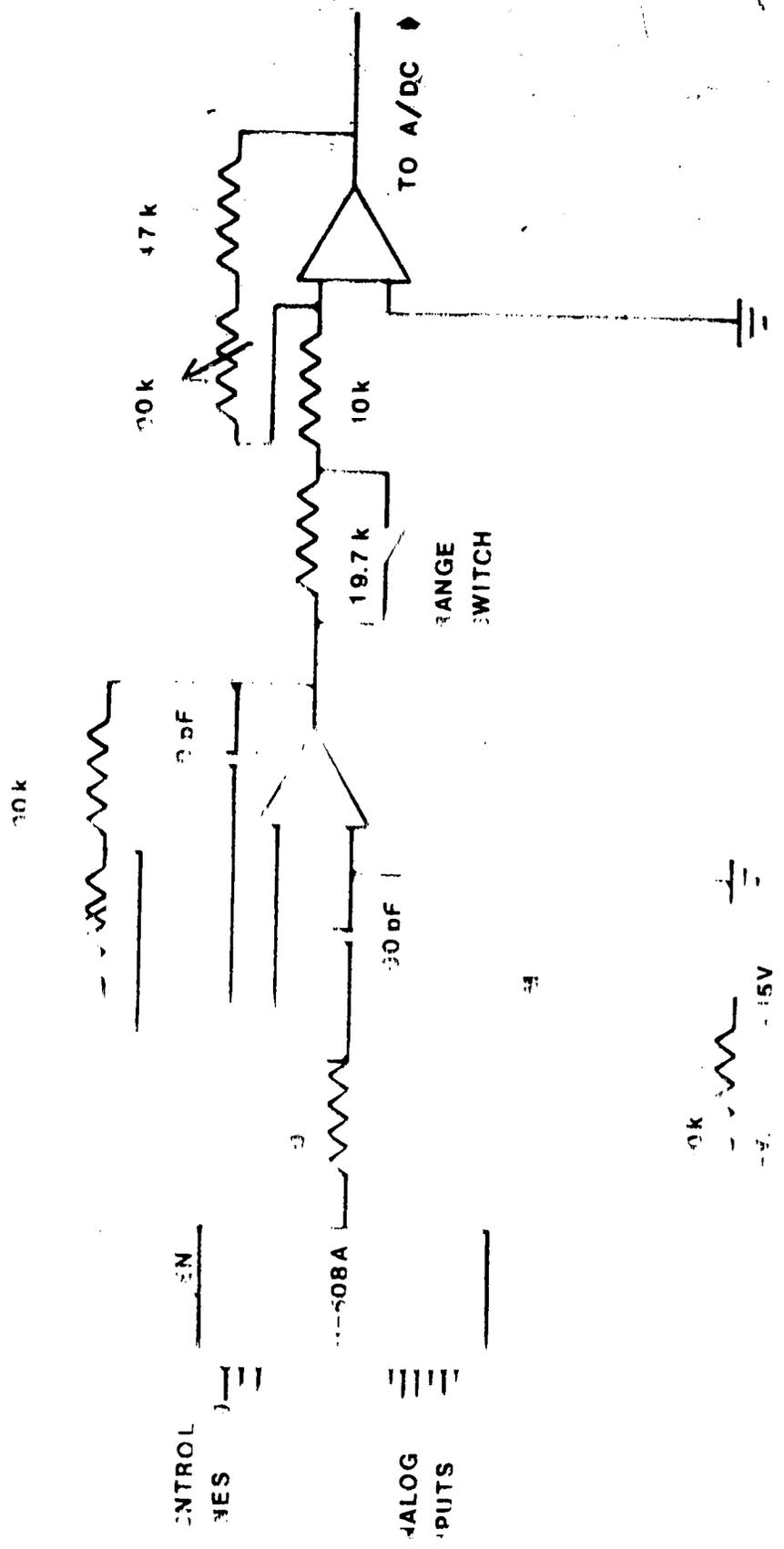


Figure 22. The pre-amplifier for the AIM 65 system.

inverted the signal and acted as a summing amplifier to allow the incoming signal to be offset by  $\pm 1$  volts. The low pass filter was included to exclude noise from exterior sources such as the inductively coupled plasma radiofrequency power supply. The second operational amplifier reinverted the signal and amplified it by 4.7 to 15 times so that the array signal could be expanded to match the full range of the analog to digital converter. The high-low range switch was added to allow a divide by 10 operation without disturbing the gain control settings of the amplifier.

### 1.2 The Analog to Digital Converter

Standard commercial devices were used. The converter was an ADC 11317 by Analog Devices, which gave a 14 bit conversion in 12  $\mu$ s. During the conversion the analog signal was held constant by a sample and hold amplifier S/H 1144. Both components were mounted on a circuit board (A-1580) from the same supplier. Controls were set on the A-1580 board to set the full range of the converter to 0-10 volts and to put the switching of the sample and hold device under the control of the  $\overline{CPHS}$  output of the converter. The A/D converter output data were read

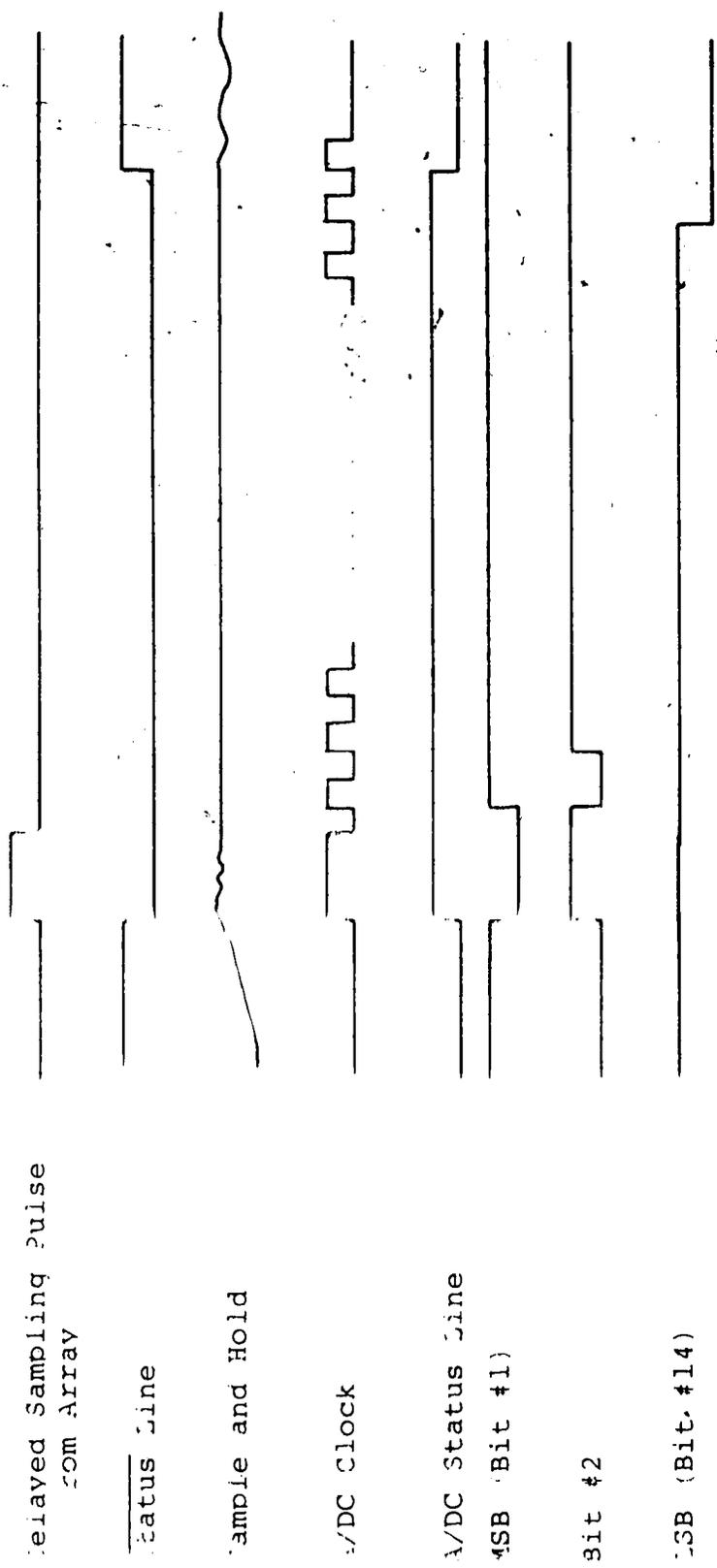


Figure 23. Timing signals for the ADC1131 analog to digital converter.

The data sampling pulse developed from the sample pulses on the array drive board RC1024S is fed to the convert command input of the A/DC. When this signal goes high the STATUS output of the A/DC is forced low to initiate the switching of the sample and hold amplifier from tracking to hold. This requires 50 to 50.5 ns to switch the amplifier and a further 1  $\mu$ s for the decay of the switching transient. The sampling pulse then goes low and its negative edge initiates the start of the conversion. The sampling pulse must be set to a width of 1.5  $\mu$ s using the 74121 monostable circuit described earlier (Figure 12) to allow sufficient time for the sample and hold amplifier to settle. During the conversion the A/DC sets the bits in order starting with the most significant. When the least significant bit has been set, the STATUS output of the A/DC goes high, unlocking the sample and hold amplifier which then returns to tracking the analog signal. At the same time the STATUS output of the A/DC goes low and this negative edge is used to trigger the microcomputer so that it receives the digital values as latched at the output of the A/D.

During operation it was found that the sample and hold amplifier was held sufficiently to hold its function and to hold its output.

### 1.3 The AIM 65 Microcomputer

This is a second generation single board microcomputer based on the 6502 microprocessor. It has several useful input/output (I/O) features which include:

- i. A typewriter style alpha-numeric keyboard.
- ii. A 20 characters wide electronic alpha-numeric display.
- iii. A 20 characters wide thermal printer.
- iv. A user I/O connector joined to a 6522 Versatile Interface Adapter (VIA). This has two 8 bit parallel I/O ports and 4 control lines. The user I/O connector also carries interfaces for cassette type tape recorders and a Teletype.
- v. A connector designed for further expansion of the computer. It carries the full address, control and data buses from the 6502 microprocessor.

The computer has a monitor in read only memory (ROM) and can be equipped with ROM based assembler and BASIC language interpreters. The computer accepts assembly language mnemonics as well as machine operating codes and this simplifies programming.

A major disadvantage of the AIM 65 as supplied is that it has only 4096 8 bit bytes of random access memory (RAM) available. This has to accommodate the system stack, all of the programming loaded and all of the data collected.

The actual interface connections between the AIM 65 and the A/DC are tabulated in Appendix 3. In summary, the lowest 8 bits of the digitized signal were acquired through the A port of the 6522 VIA and the upper 6 bits through the lower 6 bits of the B port. The STATUS output from the A/DC was connected to control line CA1. The output of the start pulse flip-flop on the RCI024S board (Figure 18) was connected to control line CB1.

## 2. Programming the Computer

The AIM 65 was programmed to carry out 2 functions. The first was data acquisition for all 128 diodes of a photodiode array. It used signal averaging and had the option of subtraction of a sequentially acquired background signal. The second, calculated signal-to-noise ratios from measurements of the data values for the same photodiode 32 times. It could handle up to 32 diodes at once in a maximum of 4 groups.

Both programs were in 3 parts. The first used BASIC to ask for parameters. The second was in machine language for the acquisition of the data. The last part was in BASIC for calculation and printout of results. The programs are listed in Appendix 4.

The data acquisition rate is governed by the time taken by the AIM to carry out the longest data acquisition

and storage loop for each photodiode of the array. In the signal-to-noise ratio program the longest loop took a minimum of 74 cycles of the microprocessor. The AIM runs at 1 MHz so this meant that at least a 74  $\mu$ s interval was required between successive samplings. In order to leave time for possible changes in programming, the sampling rate was set at 10 kHz to give a 100  $\mu$ s interval between successive diode readouts.

### 3. Setting Up the Apparatus

The spectral sources, optical systems and detectors used in our laboratory are designed to be mounted on an instrument rail bed of the type originally developed by Walters [37].

The direct reader was too cumbersome to mount directly on a rail bed but it was mounted on a fixed frame so that the entrance slit matched the height of a spectral source mounted on a rail bed. A short rail bed was placed before the entrance slit and aligned so that a source placed on it would be co-linear with the entrance slit and the centre of the diffraction grating.

#### 4. Finding the Spectral Line

The first positional reference point on the focal plane of the direct reader was made using a helium-neon laser. The laser was set up on the rail bed and the position, with respect to the scale on the exit slit mounting rack, noted for the 632.8 nm wavelength emission.

A No. 4 neutral density filter ( $1 \times 10^{-4}$  transmission ratio) was placed before the laser and a photodiode array, mounted on its carriage, set up in the focal plane.

The signal from the RC1024S board, coupled to the array, was fed to an oscilloscope and the integration time set as short as possible. The array carriage was moved and adjusted until the laser signal appeared on the oscilloscope. The carriage was then locked firmly in place on the mounting rail and the laser signal further attenuated by additional filters. The vertical adjustment on the carriage was corrected to give the maximum signal response and the horizontal focussing adjustment corrected to give the highest and narrowest peak. The position of the right side of the array carriage with respect to the scale on the mounting rail was recorded as the primary reference point.

The approximate position of the spectral line, though was calculated from the primary reference point and the reciprocal dispersion of the direct reader. This is to

the Jarrell-Ash instruction manual [38]. The array carriage and the RC1024S circuit board together with its auxiliary circuitry were moved to cover the calculated position.

A spectral source was placed on the rail bed and the spectral line located using the oscilloscope. The carriage was then locked in position and adjusted as before. The position of the right hand side was taken as a secondary reference point.

When a hollow cathode lamp was used as a spectral source, it was placed close to the entrance slit to give maximum illumination of the grating. When an inductively coupled plasma (ICP) source was used, it was run as described in Appendix I. A 1000 ppm solution of the element emitting the sought-after line was aspirated into the nebulizer feeding the plasma.

The first spectral line located with the plasma source was the calcium II line at 393.4 nm. This is a strong emission and was easily found before the illumination of the direct reader by the plasma was optimized. The illumination of the direct reader was then optimized to give a maximum signal value for this first line. (Illumination of the direct reader by a plasma source is discussed in Chapter VII.)

The initial calculation of the line position is important as the array window is only 3.25 mm wide, equivalent to a 1.8 nm spectral window. Consequently spectral emissions are not readily identifiable by their position relative to other spectral features. With experience, some reference to neighbouring spectral lines can be made by careful movement of the array carriage along the focal plane.

Initially the calculation was correct to within 1 cm but as more reference points were established, the array could be placed to within 2 mm.

Line finding was easy over the spectral range of the direct reader down to approximately 270 nm. It was noticeable that the array had to be moved closer to the centre of the Rowland circle, for correct focussing, as the array was moved to the right, towards the lower wavelength region.

At the extreme right of the dark box, line location was more difficult. The focussing adjustment on the carriage had to be moved inwards by more than 1 cm from the setting for the 632.8 nm laser line. There was considerably more depth of focus than at longer wavelengths and the signal could not be brought to such a sharp peak when viewed on the oscilloscope. The

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region (Figure 4) than at longer wavelengths. Longer integration times (up to 5 s) were required to find the lines so the results of adjustments were difficult to follow on the oscilloscope. Because the array was tangential to the Rowland circle it was not directly facing the diffraction grating (Figure 2). Consequently it was being illuminated other than normally. As the carriage focus adjustment was made, the spectral line position changed with respect to the array so that the signal as viewed on the oscilloscope moved along the array. In extreme cases, it disappeared out of the array window.

The need for focussing adjustment was caused by inaccuracies either in the placement of the focal plane mounting rail in the direct reader or in the alignment of the diffraction grating. The arc of the mounting rail did not correspond exactly to the Rowland circle of the grating. Fortunately this had been foreseen and the diode array carriage had sufficient adjustment to allow for the correction of the problem.

The single array system was used to determine some of the characteristics of a photodiode array based direct reader. Measurements were made to determine the variability of the detector, its linear range and detection limits for analysis. Several methods were

examined for separating the analyte signal from the background.

##### 5. The Variability of the Array Background

One of the limitations of the precision of any analytical determination is the variability inherent in the measuring instrument. For an electronic measurement system background consistency is very important. This was investigated for the single diode array system by observing the diode to diode variation of the signal output in the dark. The dark current itself was reduced by cooling the array to  $-22^{\circ}\text{C}$ .

Background values were measured for single runs (no signal averaging) at a series of integration times of from 0.0156 s to 64 s. Thirty six consecutive diodes near the centre of the array were selected and the means and standard deviations calculated separately for the odd and even diodes and for the set as a whole. For this series of measurements the preamplifier was set to give an output of 10 V for a saturated array. Some of the values obtained are listed in table 4 and illustrate the variability of the background signal.

Table 4. Background values for 36 diodes at -22°C.

Integration Time Seconds	Mean Values in Volts			Standard Deviation			F( Even Odd)
	Odd Diodes	Even Diodes	All Diodes	Odd Diodes	Even Diodes	All Diodes	
.01563	2.855	2.778	2.817	.01014	.01494	.04132	2.17
.25	2.059	1.984	2.021	.01373	.02675	.04362	3.80
1.0	1.893	1.825	1.859	.01423	.02780	.04071	3.82
4.0	1.321	1.282	1.301	.01411	.02825	.02953	4.01
16.0	.598	.608	.603	.01701	.03454	.02729	4.12
32.0	.905	.931	.918	.02947	.03851	.03634	1.71
64.0	1.479	1.520	1.499	.02351	.03833	.03807	2.66

5.1 Changes in the Background Mean Value

The background mean value changed as the integration time was increased. It decreased with time for about 16 and then started to increase again. The decrease was due to electronic leakage on the PC1024S board. The later increase was due to the build up of integrated dark current. Because of this background change, the absolute value of a spectral signal, with respect to ground, becomes meaningless. It has to be corrected for background change by reference to measurements made in the same area but away from the spectral signal.

This change in background level with integration time was later investigated for several array temperatures. The results are plotted in Figure 21. The temperature dependence of the integrated dark current is clearly indicated. Other experiments have shown that the linear range of the array remains steady as the background initially increases, with integration time, but is limited by the integrated dark current. The linear range for the array is only a few percent of the light intensity. The array temperature of 40°C was used to leave sufficient remaining linear range for the measurement at 1000 integration time.

5.2 Differences Between ... Equations

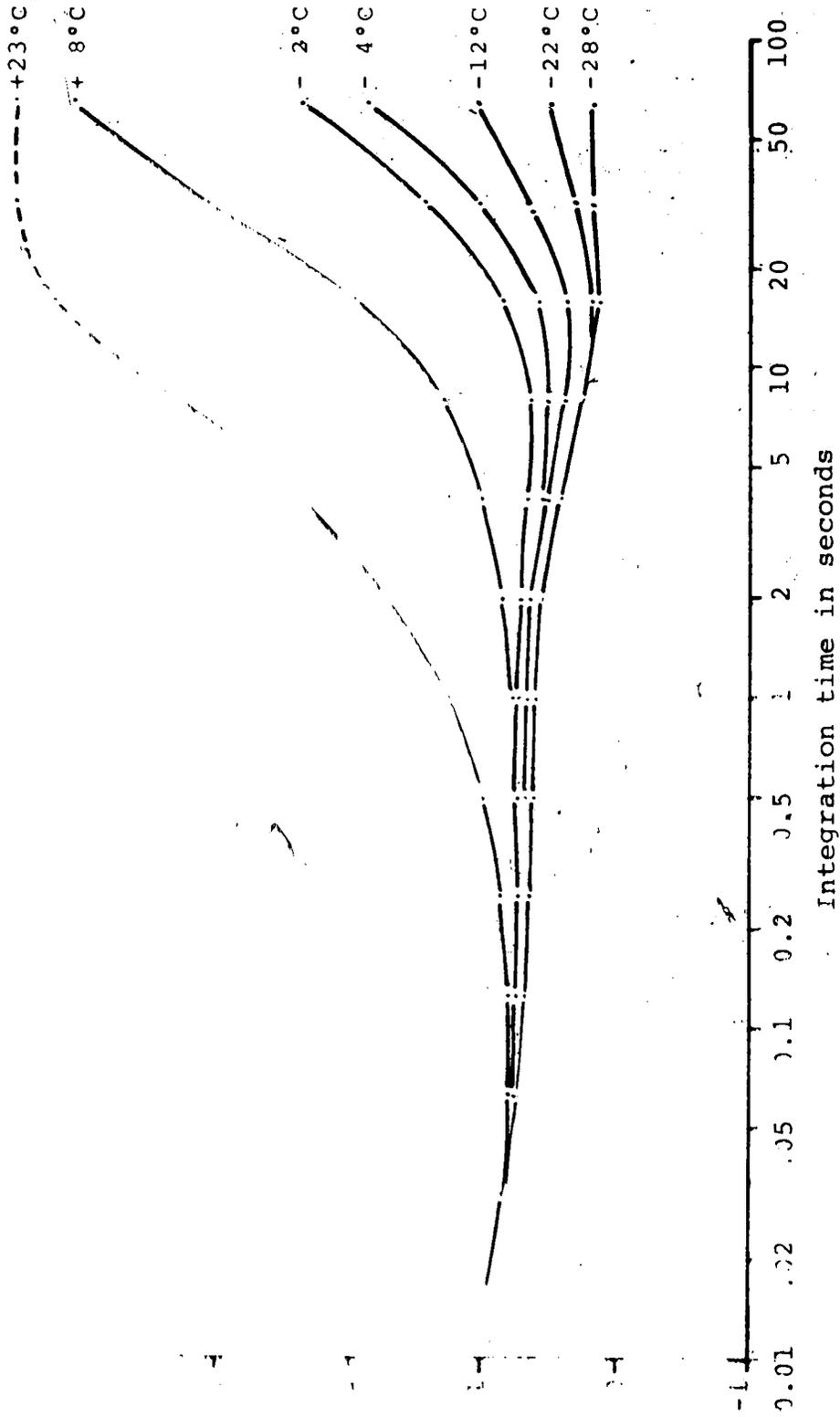


Figure 24. The dependence of background signal level on integration time and array temperature.

(variance ratio) for the even and odd sets of diodes. For the hypothesis that the odd and even diodes form separate data populations, these F values exceed the 99% confidence level for four of the values quoted in the table, exceed the 95% level for two and fail to reach the 95% for the remaining two.

The odd and even diodes are not equivalent in the background. Their readout is controlled by separate shift registers on the array. Their signals come out of the array on separate pins, use separate wires in the ribbon cable, and are processed through separate difference amplifiers, buffer amplifiers and an analog switch before they are combined into a common signal line.

This can be adjusted to the same level in the dark at minimum integration time but their dark current is not the same.

The mean values given in the table for the odd diodes were greater than those for the even diodes at short integration times but they were the same at long integration times. This may have been due to the fact that the experimenter took care to half adjust the gain of the odd diodes to the other diodes.

The variance ratio is a test of whether two data sets are from the same population. It is calculated by dividing the variance of one data set by the variance of the other. As the

integration time was increased, the amplifiers had more integrated dark current signal to work on and the gain adjustment may have been set a little low.

The F test showed that the even diodes were more variable than the odd ones. If it were just a question of an offset in their values, their variances would be similar. There is yet another adjustment to be made that would account for this difference in variability. Each shift register in the array is driven by two phase clocks called  $\phi 1$  and  $\phi 2$  (Figure 5). There are adjustments on the RC1024S board that allow the matching of the outputs of these diodes read out on  $\phi 1$  to those read out on  $\phi 2$ . This adjustment had been more accurately made for the odd diodes than for the even ones. This control does not drift significantly.

The separate variabilities of the odd and even series of diodes do increase with longer integration times and this is likely to cause problems as long integration times will be used with the weaker spectral intensities.

The variations in the background level affect the way the array is read out. Because background level drops initially as integration time is increased, the lower end of the range of the analog to digital converter cannot be touched to the background level. Consequently the full 10 bits of the converter cannot be made equivalent to the

difference in the saturated and background values for the array output.

For some measurements on the single array system, the range switch on the preamplifier was opened (divide by 3) (Figure 22) and the offset adjusted so that all background and saturation levels fell within the range of the A/DC. This would increase the effect of digitization error if it became significant. A different approach was taken later when the multi-array system was designed (see Chapter VI).

The interdiode variation, especially the odd-even variation, is very serious. It can only be adjusted at very short integration times and affects most signal measurements. Later measurements (Chapter VI) were made considering the odd and even diodes as separate populations when background levels were calculated.

## 6. Noise Measurements

Salin and Herlick [39] have reported on the standard deviation and signal to noise ratio of photodiode array detector systems. They report that, with an RF plasma source, the signal to noise ratio is independent of the signal strength away from the detection limit. This is because the major noise source is flicker noise in the plasma source and the standard deviation is proportional to the signal.

standard deviation of the array background due to dark current is independent of integration time up to 2.5 s.

The new method for controlling the array allowed measurements to be made with much longer integration times than those used previously. A hollow cathode lamp was used instead of the dark current as a source relatively free from analyte flicker noise. Standard deviations were calculated for background subtracted values by using multiple measurements of the signal for a single diode. Values are given in Table 5 for the diode at the 403.3 nm emission for manganese. The standard deviation remained constant until the integration time was increased to 8-16 seconds and then it started to increase.

The slow increase in standard deviation may be due to low frequency flicker noise as it takes at least 19 minutes to carry out a set of measurements with 16 seconds integration time. There could be slow variation in the output of the hollow cathode lamp spectral source but variability in the measurement system cannot be excluded. For these measurements the preamplifier was set for a gain of 3.3. Consequently, most of the figures in Table 5 represent variations of 1 to 3 millivolts in the outputs from the PC1024S board. This could control the lower detection limit of the diode array if other noise sources were absent. As the upper detection limit is set

Table 5. Standard deviations of a diode output with a constant source.

Integration Time Seconds	Standard Deviation (Millivolts) at			
	-28°C	-12°C	-2°C	+8°C
.0313	-	-	3.2	2.9
.0625	-	2.6	2.9	3.3
.125	3.6	2.6	3.2	2.8
.25	2.6	3.0	2.8	2.7
.5	2.2	2.8	3.0	2.9
1.0	2.6	2.9	2.5	2.6
2.0	3.8	10.9	3.3	2.7
4.0	3.4	2.4	2.5	2.5
8.0	2.6	5.1	2.8	2.7
16.0	7.9	132.	4.7	3.6
32.0	16.0	8.1	9.0	5.5

by saturation at 1 volt, the linear dynamic range of the detector system at a fixed integration time would appear to be between two and three orders of magnitude. The two anomalous results for the  $-12^{\circ}\text{C}$  series are difficult to explain. The mean values taken at the same time as these standard deviations corresponded to the expected values for these integration times yet the standard deviation values suggest considerable variation. Simulation calculations have shown that these anomalous results could be achieved by the array failing to respond to one start pulse out of the 32 in the series while the data acquisition system responded to all start pulses. However, no proof of this occurrence can be offered. The  $-12^{\circ}\text{C}$  series was the first series run and the effect did not occur in the other 3 series.

#### 7. Proportionality of the Array Signal to Time

A diode array, run at a fixed integration time, has its upper detection limit set by the saturation of the array and its lower detection limit set by the readout noise level. In order to extend the dynamic range, the integration time is changed to bring the output signal within these limits. It is assumed that the array signal will be proportional to the product of the integration time and the light intensity. Horlick and Coddling [40] have reported linearity within 1%.

The validity of the assumption was demonstrated by the following experiment.

A hollow cathode lamp intended for steel analysis by atomic absorption was used as a steady light source. The array, cooled to  $-22^{\circ}\text{C}$ , was set up to detect the manganese triplet at 403.1, 403.3 and 403.4 nm. The preamplifier was set to give an array saturation value of approximately 10 volts at the A/DC. The entrance refractor plate of the direct reader was adjusted to get a maximum signal value for the centre peak (403.3 nm), by moving the centre of the peak to correspond to the centre of a photodiode. Measurements were made over a range of integration times of from 0.0156 s to 64 s by averaging 10 scans with 10 scans of dark current subtracted. The results are graphed in Figure 25. The array signal was proportional to time over more than two orders of magnitude, and for the centred 403.307 nm peak to three. Fortunately, the signal output from the hollow cathode lamp was strong enough to demonstrate, within the available integration times, both the upper limit of linearity due to saturation and the lower limit shown by the deviation of the weakest peak (403.45 nm) as its measured signal approached the noise level of the array. The linear range of the array corresponds to that suggested in the section on noise measurements.

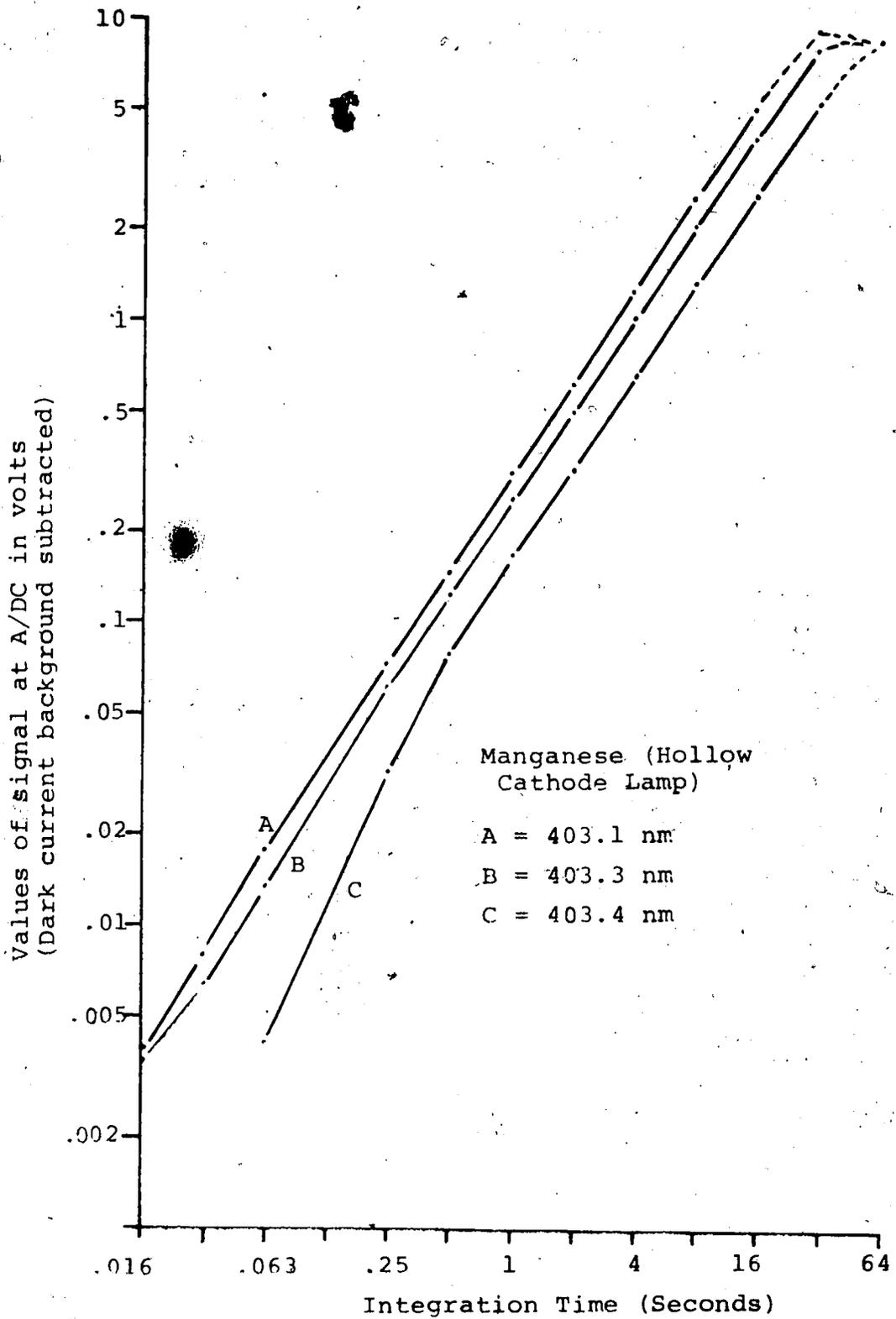


Figure 25. The proportionality of the array signal to integration time.

The validity of the proportionality assumption allows the light intensity falling on a photodiode to be represented by the value of the output signal (after suitable background corrections) divided by the integration time. This gives a measure of the total light intensity affecting a single diode normalized to a 1 s integration time.

The linear detection range of the photodiode array direct reader should then be obtained from the product of the linear range of the array and the available range of integration times.

#### 8. Spectral Measurements Using an ICP Source

The performance of an analytical instrument can only be tested properly by using it for analysis. The single array system was used for independent measurements of 6 elements. Information was obtained on the linearity of the system, detection limits and on the use of simple methods of background correction.

Separate solutions were prepared for cadmium, calcium, magnesium, manganese, strontium and zinc, all at 1000 ppm concentration. These were diluted in tenfold steps to give a series of solution concentrations extending down to the expected detection limit for each element. Double distilled and deionized water was used.

for all dilutions. The solutions were aspirated into the spray chamber of an inductively coupled plasma source. (Operating conditions of the ICP are given in Appendix 1.) The spectral emissions of the 6 elements chosen fall in the wavelength range of 238 to 408 nm.

The preamplifier to the analog to digital converter was set in the low gain position to allow the use of the whole range of integration times from 0.0156 s to 64 s. All data were the signal averaged values for 5 consecutive diode array integrations. Where the background was corrected by subtracting the signals generated by aspiration of water, this was done immediately by the use of the subtraction loop in the data acquisition program (Appendix 4).

### 8.1 Measurements with Calcium as Analyte

The calcium II line at 393.4 nm is a very intense emission in the ICP and was chosen to illustrate the linear range of the detection system that could be obtained by varying the integration time. The system responses are shown in Table 6. The parameter recorded is the peak height voltage, at the A/DC, normalized to a 1 second illumination by dividing by the integration time.

The first set of values (A) are the water background subtracted values. The second set (B) is similar to set (A) but has been further corrected using a factor obtained

Table 6. Photodiode response to calcium 393.4 nm. Values are in volts at the A/DC normalized to a 1 second integration time.

PPM (PPB)	A Water Signal Subtracted	B A + Correction	C Corrected only
1,000	87.4	86.5	79.9
100	14.5	14.4	--
10	1.58	1.57	1.59
1	.152	.149	.149
(100)	.0139	.0138	.0136
( 10)	.00153	.00155	.00153
( 1)	.000254	.00020	.00013

from the values for off-peak diodes close to the response peak. The third set (C) are values without the water background subtraction but using the correction factor obtained from off-peak diodes. The use of water background subtracted values required about 12 minutes to run at 64 s integration time with the possibility of low frequency flicker noise affecting the subtraction. The off-peak correction factors for calcium were calculated from groups of 7 and 8 consecutive diodes starting 7 diodes away from the peak. They helped to compensate for any flicker noise in the system other than that due to the analyte.

The results listed in Table 6 indicate that the use of the off-peak diode generated correction factor gives linearity as good as that obtained using the water background subtraction method. This is subject to certain reservations. The array must be free from defects (glitches) in the peak region and in the background evaluation region. The peak must not be subject to interference from wavelength dependent spectral features such as argon lines and OH molecular spectra unless they can be corrected for. The response of the individual diodes to light must not vary significantly. Hog [41] reported that for an earlier type of diode array, the RMS value of the interdiode variability was about 0.1% and

that the end-to-end variation over 256 diodes was of the order of 2%.

The variation in the integrated dark current among the group of diodes must be insignificant. This is not true at room temperature as observed by Vogt [25] and others, including this current work. It can be calculated that the thermal generation of hole-electron pairs and hence the integrated dark current is reduced by a factor of 11 by cooling the array from +23°C to -20°C. As a high quality array, running with a gated oscillator, it takes about 16 seconds to saturate with dark current at 21°C. An array at -20°C and integrated for 64 seconds has 63% of its dynamic range taken up by dark current. Dark current measurements would have to be made for each individual array to determine the variability as there is

considerable variation of this property between arrays.

The odd order diode differences must also be considered when calculating the off peak correction factor. The difference in length of the odd and even diodes must be considered to form 2 separate populations. In the case of the off peak background, the off peak correction factor is calculated from the ratio of the off peak to the on peak diode

The off peak correction factor is calculated from the ratio of the off peak to the on peak diode

a liquid nitrogen cooled array with integration times of over one hour to study star spectra.

The value given in Table 6 for the water background subtracted signal for 1 ppm calcium solution was actually a mean value for 6 determinations at different integration times. The individual parameter values are shown in Table

The values in Table 7 were calculated from voltages at the A/D converter ranging from 20 millivolts to 4.423 volts depending on integration time. When this is considered, the values are remarkably close. Digitizing error is not involved. The value of the least significant bit of a 14 bit A/D converter operating over a 10 V range is 0.6 mV. This would cause, at the most, a 3% error in a 20 mV signal. The odd group pattern contribution was calculated separately and found to be insignificant. Some of the variation with integration time may be due to the multiplication of signal to low signal levels and short integration times. This should not be a serious problem and analysis of signal to noise will be presented for long integration times.

The use of longer integration times to improve detection limits is illustrated in Table 8.

The values are for a relatively low concentration. They are the standard deviation subtracted and were calculated

Table 7. 1 ppm calcium measured with various integration times. Values are volts normalized to 1 second integration time.

Seconds Integration	A Water Subtracted	B A + Correction
32.0	.1382	.1378
16.0	.1490	.1487
8.0	.1499	.1483
2.0	.1551	.1553
.5	.1543	.1519
.125	.1624	.1529
Mean	.1515	.1492
Standard Deviation	.0081	.0062

Table 8. Signal to noise ratios with a low analyte concentration (Ca, 10 ppb).

	Integration Times		
	16 s	32 s	64 s
Signal to Noise Ratio	5.6	10.7	24.1
Mean Volts	.0221	.0574	.0892
Standard Deviation	.0040	.0054	.0037
<u>Mean</u> Int. Time	.0014	.0018	.0014

from 32 successive signal values for the same diode (and 32 water background values subtracted).

Close to the detection limit the limiting noise level is due to the measurement system which is independent of the analyte concentration and the integration time (if the array is cold enough). The analyte signal is proportional to integration time so, as the latter is increased, the signal to noise ratio is increased. If the detection limit is taken as the concentration at which the signal to noise level is 3, then the table values indicate a detection limit of 5.4 ppb decreasing to 1.25 ppb as the integration time is quadrupled from 16 to 64 s. The ultimate low level of the detection limit would appear to be governed by the limit of the integration timer circuit, the electronic stability of the system and the operating temperature of the array.

A logarithmic plot of the diode array response to the CdII line at 303.4 nm is shown in Figure 26. For this strong emission, it is possible to cover more than 5 orders of magnitude of concentration values by combining control of integration times with the dynamic range of the photodiode array.

The curvature of the line at high concentrations may have been partially due to self absorption but it certainly was partially due to error in the calculation of

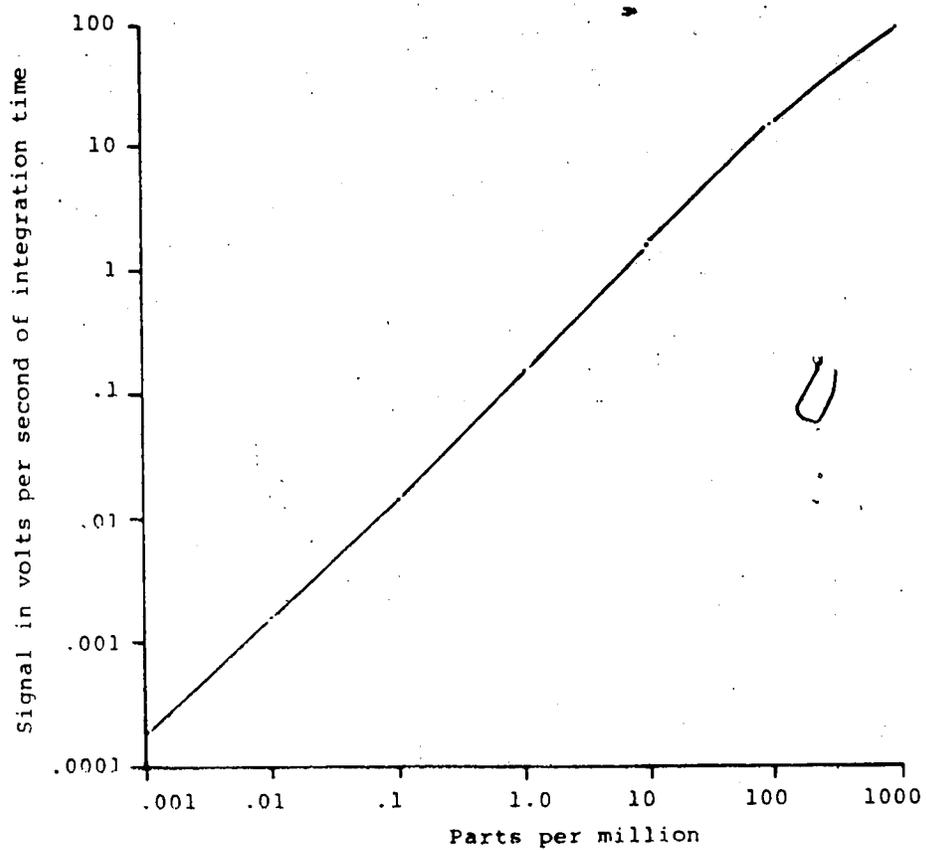


Figure 26.

The diode array response to calcium concentration for the CaII 393.4 nm emission.

the base line value from off-peak diodes. This was caused by collision broadening of the spectral line within the plasma source. This effect is increased for some emissions as the linear Stark effect occurs due to interaction with the plasma electrons [12]. This line was sufficiently broad for the 1000 ppm concentration that its wings overlapped onto the diodes used to calculate the off-peak correction factor. It can be seen from Figure 27 for the signal from 1 ppb concentration that the broadening effect persists down to very low calcium concentrations. In summary, the calcium experiments have shown:-

- i. The measurement system has good linear dynamic range for a strongly emitted spectral line.
- ii. In favourable circumstances, the base line used for measurements can be obtained from the same array measurements as the analyte signal.
- iii. Detection limits are improved in proportion to increases in integration time.
- iv. The noise level near the detection limit is again due to the detection system.

## 8.2 Measurements with Magnesium as Analyte

Magnesium has its two strongest plasma emission lines close enough together for a single array to record both of them. At 280 nm they are of shorter wavelength than the calcium line already discussed.

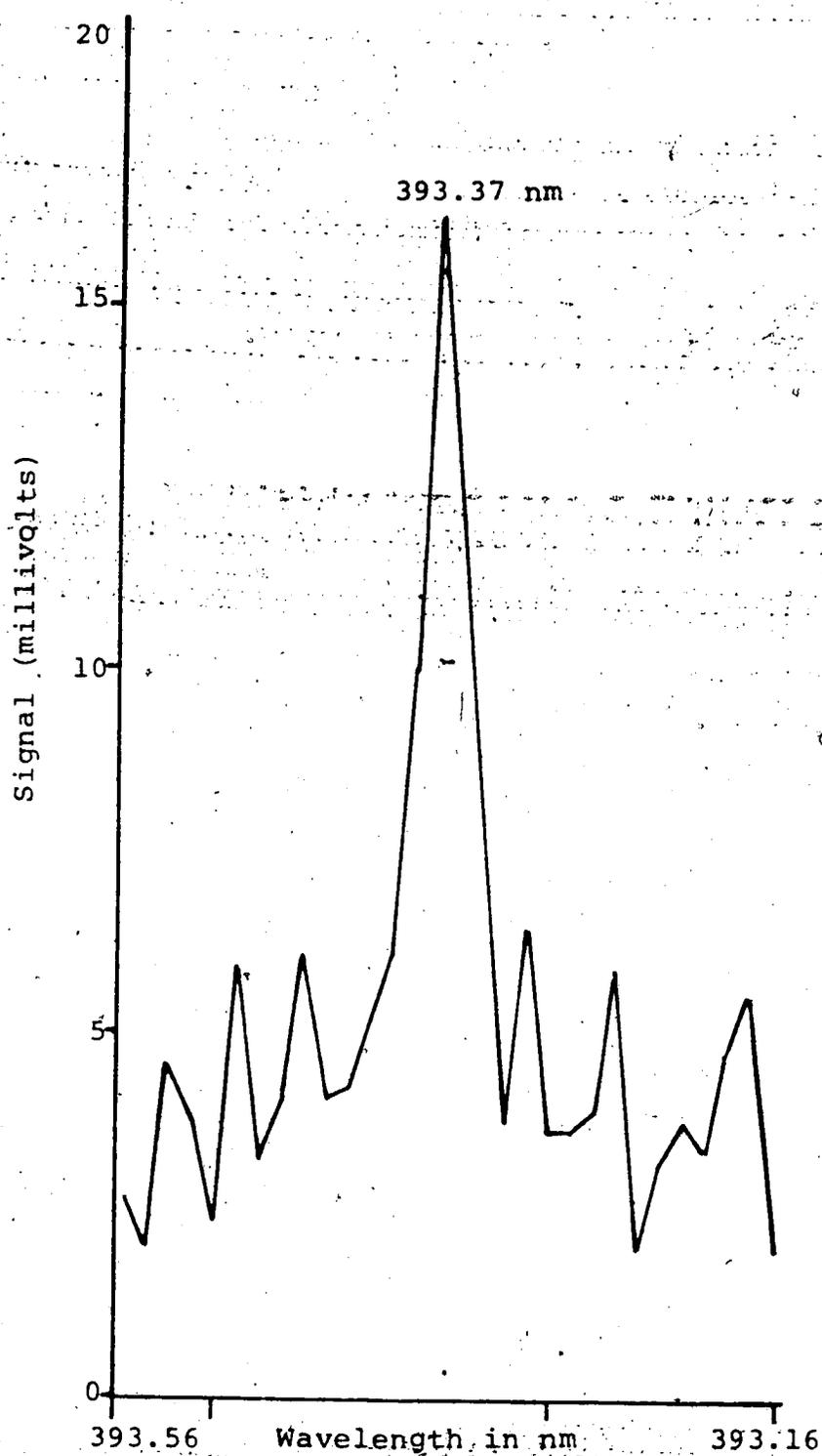


Figure 27. The Ca II peak at 393.4 nm for 1 ppb calcium.

The water subtracted values are given in Table 9. All of the values in the table are water background subtracted data, with and without the use of off-peak diode correction. The two peaks were 53 diodes apart on the array and the off-peak correction factor (background level) was taken from 15 diodes in the centre of the gap between them. Values are also shown for attempts to measure peak area by summing values for the peak diode with those for 5 diodes on either side. The off-peak correction factor was then applied 11 times. The peak area concept was considered in case it had to be used to correct for geometric changes in the position of the diode array. The values for the 2 spectral lines correspond to each other for concentrations of 100 ppm and less. The peak area calculations correspond to approximately three times the value of the central diode signal except at the lowest concentration levels, where they lose precision.

Kubota [42], using a microchannel-plate, image intensified, diode array, has used signal to noise ratios to show that the use of peak area is less precise than peak height. He explained it as due to the increased significance of detector dark current variation and source background variation at the wings of the peak.

Figure 28 is the logarithmic plot of the array response to the two lines.



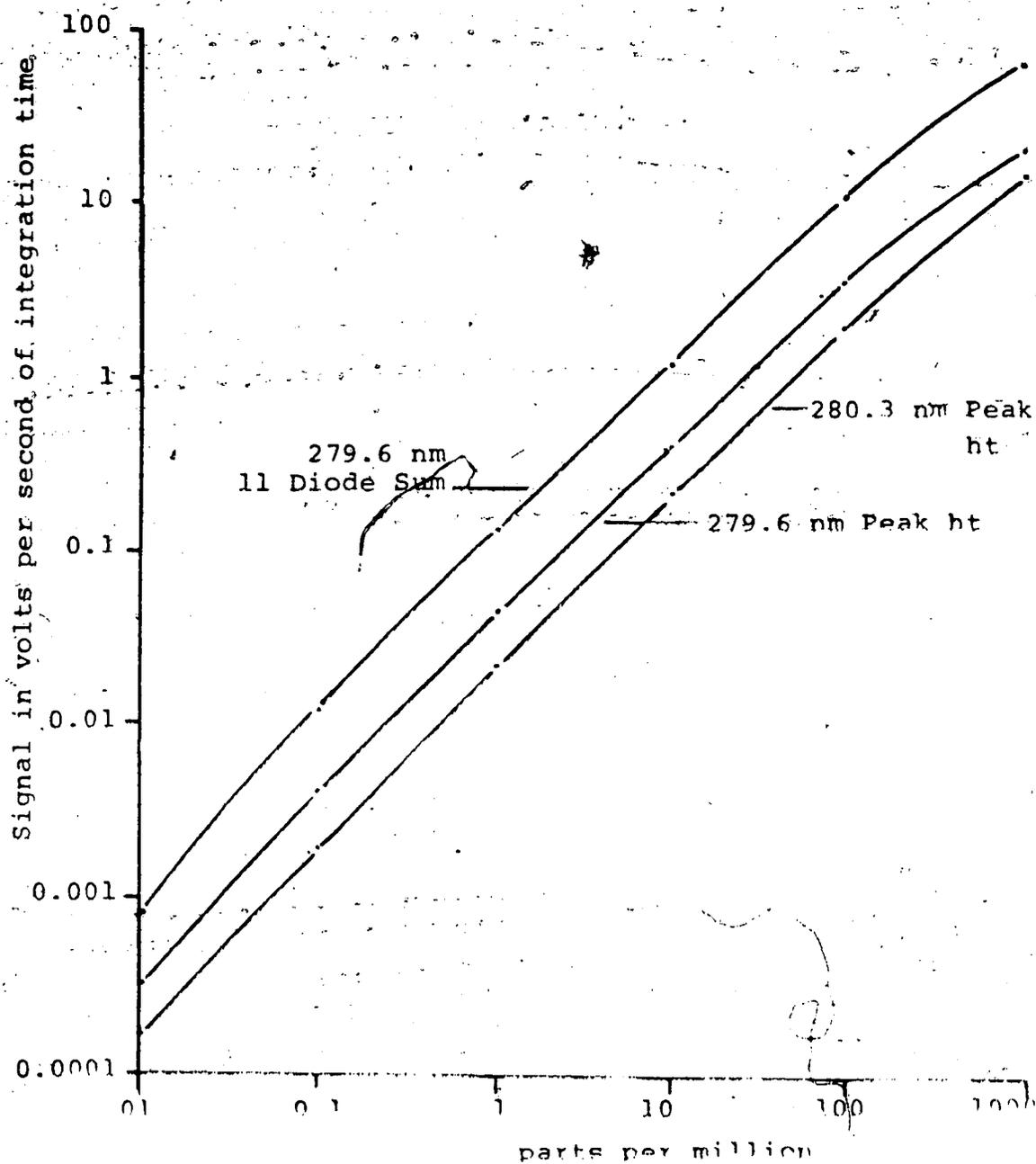


Figure 28. The diode array response to magnesium concentration for the MgII emissions at 279.6 nm and 280.3 nm.

A signal to noise measurement was made for the 10 ppb concentration based on the method of repetitive measurements of the peak value and water background subtraction. The value obtained for the signal to noise ratio was below 1, suggesting that the solution concentration was well below the detection limit. The signal averaged values for 5 runs shown in Figure 29 show that the peaks are still well above the detector noise level as obtained from values of successive diodes in the background.

The repetitive determinations method for signal to noise ratio takes 70 minutes to run with 64 s integration times and is sensitive to low frequency variation such as a DC level drift. If the analyte peak is measured with respect to the variation among the diodes of the same measurement it can still be evaluated regardless of DC level drift.

In summary the magnesium experiment has shown:-

- i. The responses to two spectral lines maintain a close ratio over several orders of magnitude.
- ii. Peak heights have better precision than peak areas at low analyte concentrations.
- iii. Signal to noise ratios obtained from repetitive measurements of a single diode output can give a false indication of the detection limit.

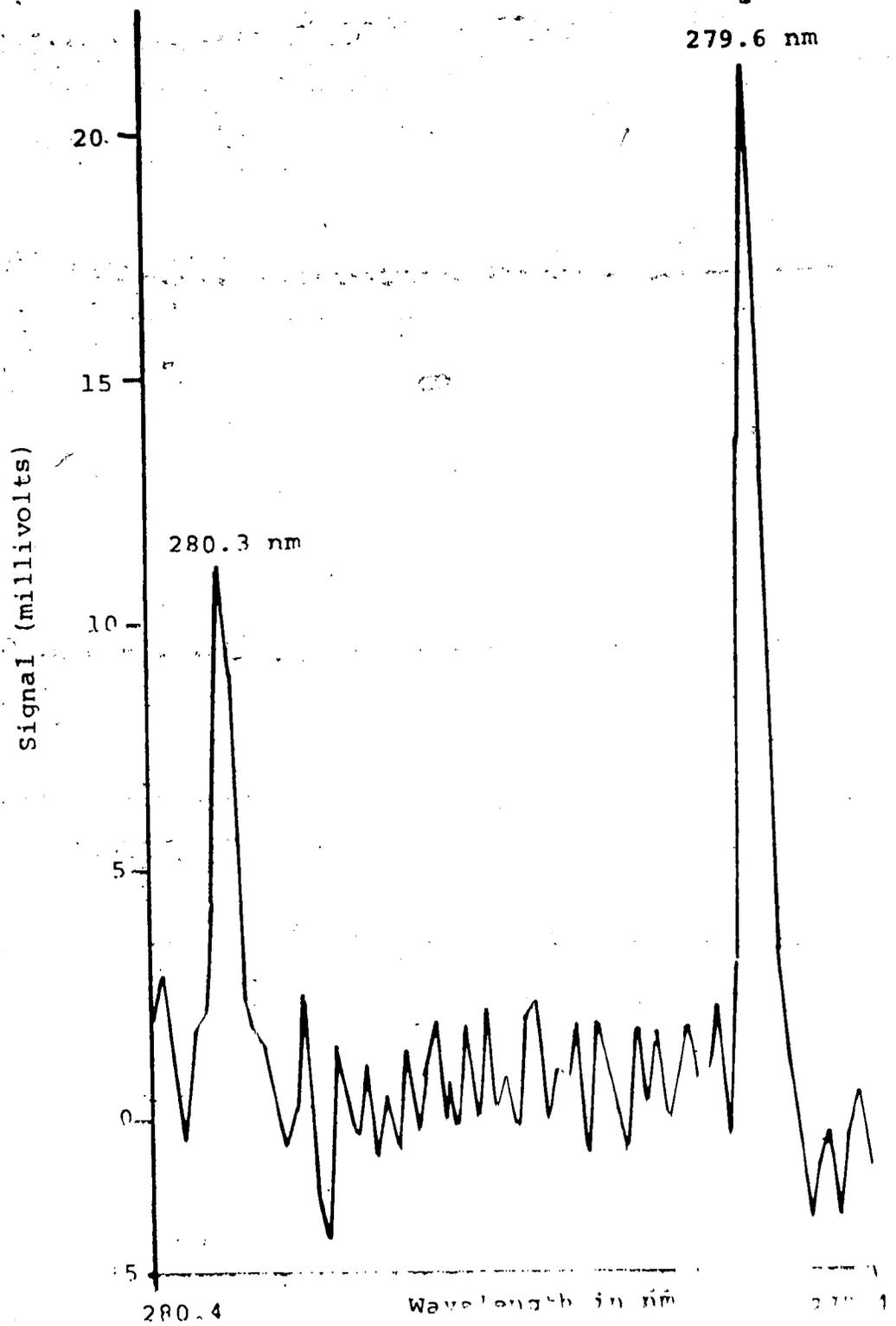


Figure 29 The magnesium peaks at 279.6 nm and 280.3 nm for 10 ppb magnesium

### 8.3 Measurements with Cadmium and Zinc as Analytes

These elements were chosen because the spectral lines used for their analysis are much lower in wavelength than those of the other elements chosen. The cadmium II 226.5 nm and zinc I 213.86 nm emissions were very difficult to locate as they were low in intensity and required considerable focussing adjustment of the array carriage. The diode array responses are given in Tables 10 and 11. The response curve for both cadmium and zinc is shown by Figure 30. The zinc peak at 1 ppm concentration is shown by Figure 31.

The array responses to these elements was expected to be lower than for calcium but the values obtained were much lower than expected.

### 8.4 Measurements with Manganese as Analyte

The manganese lines chosen were the manganese I triplet at 403.08 nm, 403.31 nm and 403.45 nm. These same lines had been previously used with the hollow cathode lamp source to establish the linearity of the array. They are close enough together to be recorded simultaneously and illustrate the resolution capable with the diode array detector. The array responses are given in Table 12. All values were water background subtracted and adjusted with the off peak correction factors. The response curves are given in Figure 12. Measurements across the three peaks,

Table 10. Photodiode response to cadmium. Values are volts at the A/DC normalized to 1 second integration time.

PPM	Water Subtracted	Corrected Water Subtracted	Corrected Only	11 Diode Sum
1,000	.241	.238	.244	.769
100	.0278	.0276	.0258	.0906
10	.0031	.0031	.0031	.0102

Table 11. Photodiode response to zinc. Values are volts normalized to 1 second integration time.

PPM	Water Subtracted	Corrected Water Subtracted	Corrected Only	11 Diode Sum
1,000	.403	.401	.421	1.39
100	.0436	.0447	.0449	.146
10	.00537	.00535	.00538	.0165
1	.00049	.00045	.00044	.00212

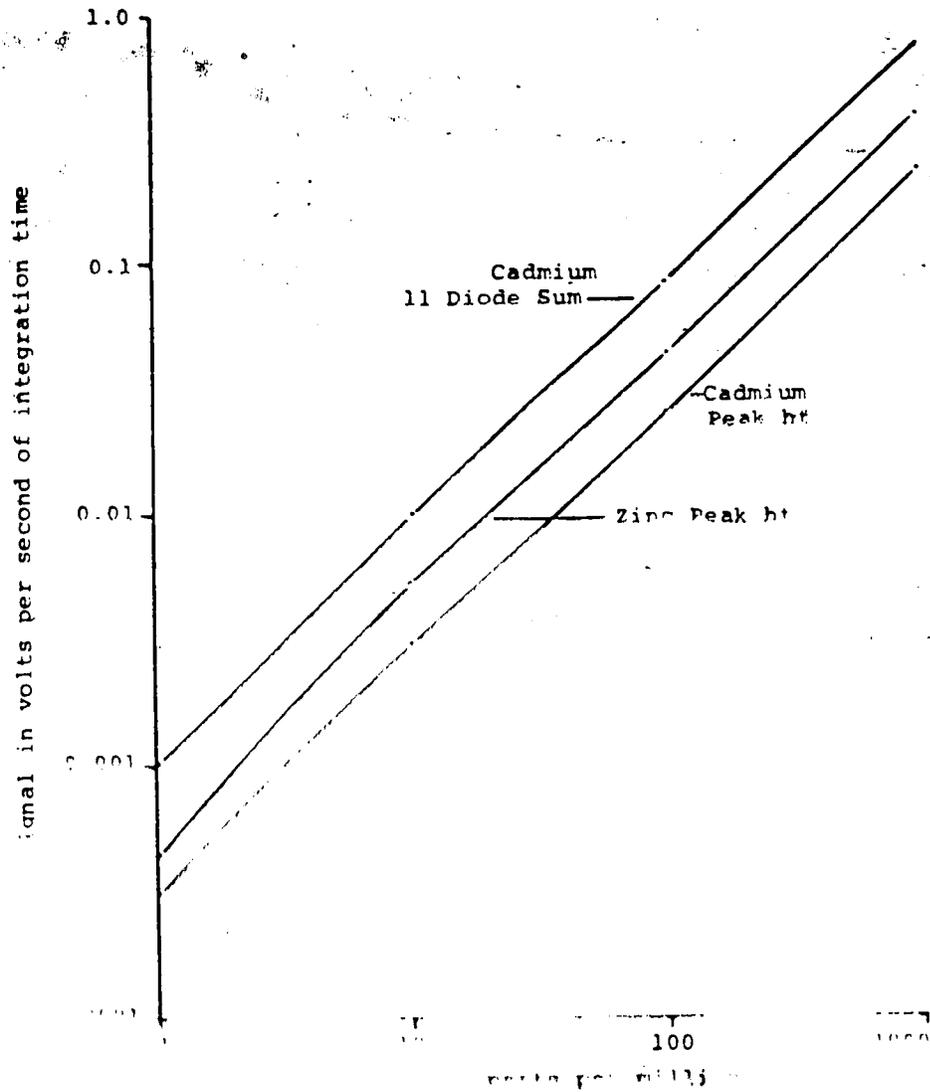


Figure 30 The diode array response to cadmium and zinc concentrations for the 11 diode sum and the 11 diode sum line.

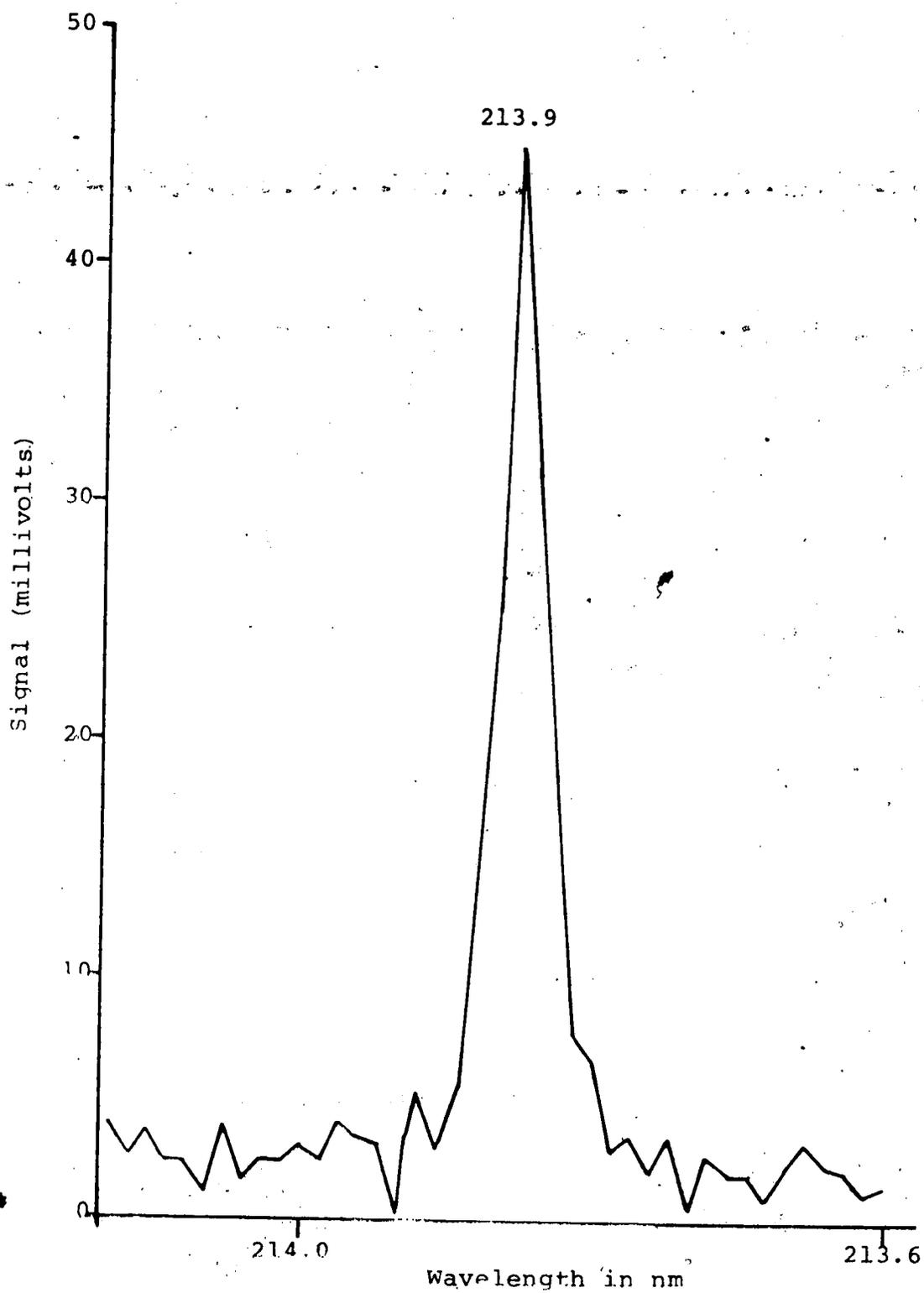


Figure 31. The zinc peak at 213.9 nm for 1 ppm zinc.

Table 12. Photodiode response to manganese. Values are volts at the A/DC normalized to 1 second integration time.

PPM (PPB)	403.08 nm			
	403.45 nm	403.31 nm	Peak Height	11 Diode Sum
1,000	.875	1.39	1.76	3.27
100	.070	.126	.154	.325
10	.0075	.0132	.0184	.0330
1	.00067	.00109	.00177	.00313
(100)	.000054	.00019	.00017	.00037

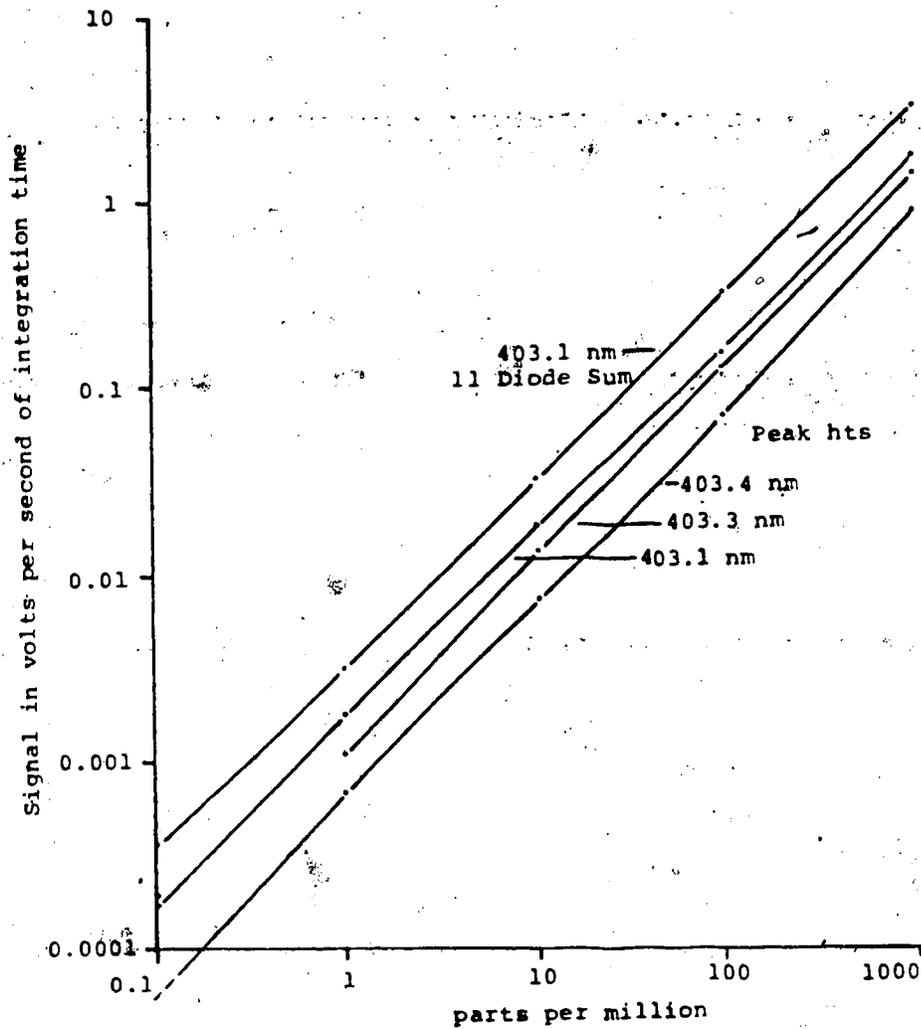


Figure 32. The diode array response to manganese concentration for the MnI triplet at 403.1 nm, 403.3 nm and 403.4 nm.

showing the resolution, are illustrated by Figure 33 for the 1 ppm concentration of manganese. The 11 diode sum values (peak area) were twice the value of the peak height, compared to triple the peak height for magnesium, cadmium and zinc. The manganese lines appear to be narrower than those of the other elements. This is probably due to the position of the manganese lines which are formed close to the normal of the centre of the grating. Here astigmatism is less than at the lower wavelength positions on the focal plane.

In summary, the manganese experiment has shown:-

- i. An example of base line resolution for two spectral lines separated by only 0.14 nm.
- ii. An example of a much narrower spectral line than those obtained with the other elements examined.

#### 8.5 Measurements with Strontium as Analyte

Strontium was chosen as it emits about 100 times as intensely as the manganese lines in the same spectral region. Like the calcium II line at 393.4 nm, strontium II 407.8 nm is affected by the linear Stark effect and should have a completely different profile than the manganese lines. The experimental values are given in Table 13.

The loss of linearity at the high concentration is mainly due to self absorption in the source as the off-

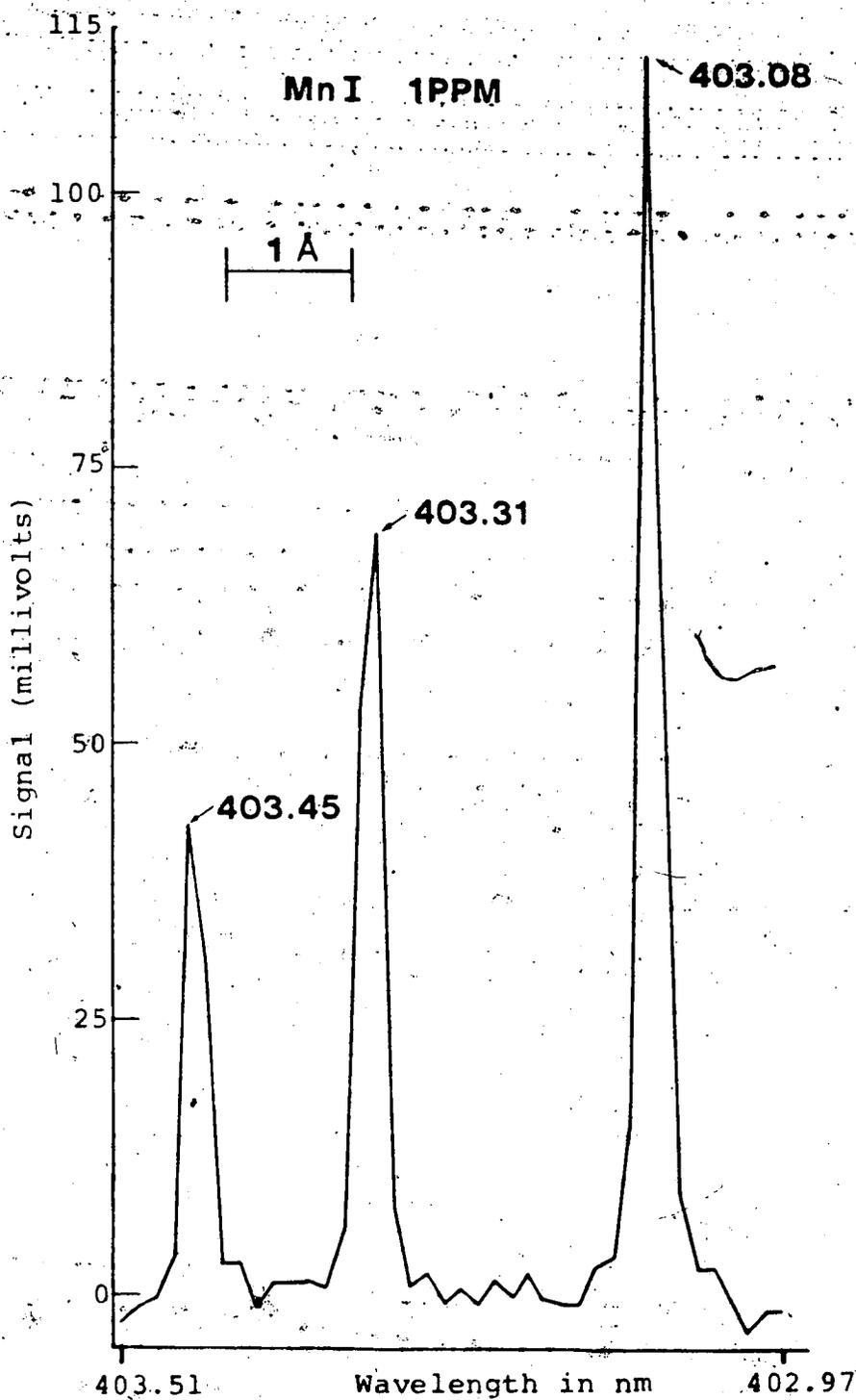


Figure 33. The manganese 403 nm triplet at 1 ppm manganese.

Table 13. Photodiode response to strontium. Values are volts at the A/DC normalized to 1 second integration time.

PPM (PPB)	Water Subtracted	Corrected Water Subtracted	Corrected Only	11 Diode Sum
1,000	74.5	74.2	75.5	224.5
100	15.0	15.0	14.8	43.1
10	1.80	1.79	1.79	5.02
1	.179	.179	.181	.50
(100)	.020	.020	--	.062
( 10)	.00165	.00174	.0021	.0054

peak correction factor was calculated from diodes well away from the peak. The eleven diode sum values were approximately three times the peak height. The peak for the 10 ppb concentration is shown as the solid line in Figure 34. The dotted line is for the 403.8 nm line of 1 ppm concentration of manganese, drawn to the same scale and is included to give an indication of the degree of broadening of the strontium line.

#### 8.6 Discussion of the Detection Limits Found

The photodiode array responses for spectral lines in the centre of the direct reader were excellent but those for cadmium and zinc were very poor. A table of detection limits of 70 elements for analysis by the inductively coupled plasma has been published by Winge, Peterson and Fassel [43]. The diode array was able to detect elemental concentrations close to those published for spectral lines in the centre of the direct reader focal plane, but not for those to the right side, in the ultra-violet.

Calculations have been made to determine the concentration limits for the diode array direct reader by a similar method to that used for the published results. Response signals were taken for solution concentrations sufficiently high above the detection limit that confidence in the values obtained was high. The concentrations chosen were still low enough for the

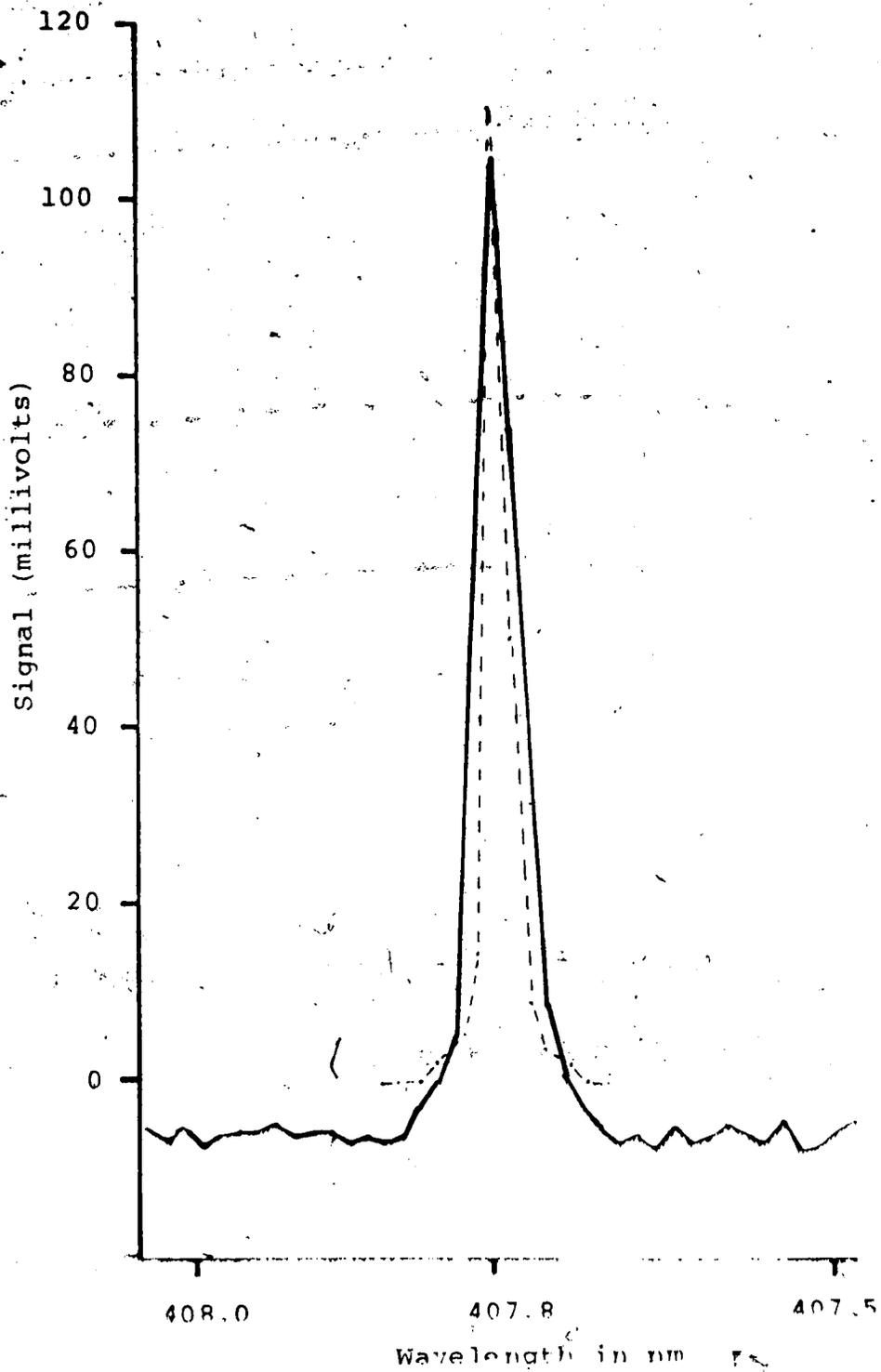


Figure 34

The strontium 407.8 nm line at 10 ppb strontium  
The dashed line is the 403.8 nm line for 1 ppm  
Mn drawn to the same scale to show the Sr line  
broadening.

limiting noise to be due to the measurement system so that the same noise level could be applied at the detection limits. The noise values (standard deviations) were calculated from the values of off-peak diodes. The detection limit was calculated as that concentration at which the signal level would equal three standard deviations of the background signal. The detection limit values are calculated and compared to the published values in Table 14. (The standard deviation for calcium was high as the off-peak diode values used to calculate the noise level were still on the wings of the broadened line. Consequently the noise would contain some contribution due to the calcium concentration.)

As low values for detection limits are desirable, values in the last column of the table of greater than one favour the diode array system. Values of below one do not.

The comparison values are obviously wavelength dependent as they change by 2 orders of magnitude as the wavelength decreases from 407.8 nm to 213.8 nm. This indicates an instrumental effect. Talmi and Simpson [23] have published a quantum efficiency curve that indicated that the photodiode quantum efficiency at 210 nm is 75% of that at 400 nm. Salin and Horlick [39] reported that the detection limit for zinc was 50 times that of calcium when

Table 14. Comparison of detection limits with published values.

Element Name	Diode Array Values							Det. Limit Ref. [43] PPM	Ratio (Ref. [43] Diode Values)
	Test Conc.	Peak Height (V)	Std. Dev. (V)	S/N Ratio	Calc. Det. Limit PPM	S/N Ratio	Calc. Det. Limit PPM		
As 407.3 nm	.1 ppm	1.281	.0011	1,165	.00026		.00042	1.6	
Mn 403.3 nm	1 ppm	.070	.0012	58.3	.051		.047	.92	
Mn 403.1 nm	1 ppm	.113	.0012	94.2	.032		.044	1.4	
As 393.4 nm	.1 ppm	.382	.0020	441	.00068		.00019	.28	
Ag 280.3 nm	.1 ppm	.121	.0015	80.7	.0037		.00030	.081	
Ag 279.6 nm	.1 ppm	.262	.0015	175	.0017		.00015	.088	
As 226.5 nm	10 ppm	.199	.0010	199	.15		.0034	.023	
Mn 213.8 nm	10 ppm	.343	.0012	286	.11		.0018	.017	

using a diode array with a monochromator. The diode array direct reader gave a ratio of 154 to 1. Consequently the use of a photodiode detector to replace a photomultiplier tube was not responsible for the signal loss. The real reason for the loss in response at low wavelengths lies in the age of the instrument.

The diffraction grating of the diode array direct reader was blazed for 360 nm [44]. The luminosity of a blazed grating falls off rapidly on the short wavelength side of the blaze [45] so the diode array cannot respond to light that it doesn't receive. The grating was blazed for this wavelength because it was supplied with DC arc and AC spark spectral sources. These used classical spectral lines that were originally established for their photographic response and were generally of longer wavelength than most useful lines from the ICP. This instrument was designed at least 3 years before the introductory papers on the plasma source were published by Greenfield [46] and Fassel [47].

By contrast, Winge's instrument [43] was designed for the ICP source with a diffraction grating blazed for 250 nm emission. This blaze is now used because the most prominent lines for 45% of the elements usually analyzed with the ICP source are in the 200 to 250 nm region

Consequently, the low response obtained for the diode array in the ultraviolet region must be considered as an instrumental problem due to the grating. It should not be considered as a barrier to its acceptance as a direct reader detector. Later work has confirmed that the limitation is due to the grating by showing stronger signals for cadmium and zinc measured in the ultraviolet compared to the same elements measured in the visible region.

## CHAPTER V

### A MULTI ARRAY SYSTEM

The experiments with the single array system have shown that the photodiode array can be operated to give similar detection limits for emission spectroscopy as the photomultiplier tube. A direct reader has to have several spectral windows in order to measure the emission from several elements simultaneously. This requires a more complex control and data logging system than was used for the single array system.

Six 128 diode arrays were available and a system was required that would run all 6 under computer control for readout and data storage. Additionally, every array had to be supplied with power, a cooling system and control signals. All of the supply lines had to be flexible to allow the array to be moved round the direct reader focal plane to suit the analytical task.

#### The Data Logging Method

In comparison, photomultiplier tube based direct readers use a separate detector tube per element. It

simultaneously records the time integrated values for the anode current for each tube in analog form. Then it sequentially processes the stored data, element by element. Because the light detector and the signal storage device are separate parts of the circuit, both can have a large dynamic range. This, in turn, allows the signals on all channels to be integrated for the same length of time.

A diode array works differently. The individual diodes are both detector and signal storage devices. In order to obtain a large dynamic range, the integration time must be varied. When the integration time has elapsed, the data processing system must accept the analog signals from the diode array circuit board, digitize them, and store them, all in real time.

A data loading system can only handle one signal at a time so to have several arrays completing their integration times simultaneously and competing for a single analog to digital converter would be a calamity.

One approach would be to have an independent data acquisition system for each array and a master computer to control them all. For six arrays, this would require not only seven microcomputers but in addition, six high speed analog to digital converters, each with its own sample and hold amplifier, and probably cooling fan, and efficient

direct current power supply at several voltages to drive them all.

The alternative approach that was chosen used a single microcomputer and avoids readout clashes by careful control of the integration times. This was done by allowing the integration times to be increased in a stepwise fashion with sufficient time allowed in each step for readout of all six photodiode arrays.

## 2. The Apple II+ Computer

The AIM 65 microcomputer, although it adequately processed the data from a single photodiode array, was not suitable for the more complex task of handling six arrays. Its limited amount of random access memory (RAM) could have been extended but its slow rate of communication with off-line systems could not easily be improved. Sequential searching of cassette tapes for programs and data is a very slow process. Interfacing with the operator had to be done through the small onboard printer as the single line electronic display could only carry a limited amount of information at any one time. Additionally, the AIM is an engineer's development machine and the little supporting peripheral hardware that is available has a limited market and is consequently expensive.

The Apple II+ is a general purpose microcomputer that uses the same type of microprocessor (6502) as the AIM but it is better designed for rapid and easy interfacing with both the operator and peripheral devices.

The main circuit board of the Apple does not have any built in input/output (I/O) devices. However, it does have the necessary interfaces for easily fitting such devices. The interfaces are shown in Figure 35.

The power, speaker and keyboard connectors are used internally by the computer. The video output connector is a standard RCA phono jack that is usually connected to a video monitor. The game I/O connector is a standard 16 pin DIP socket. It is designed to interface with hand held control devices for playing video games but it is very useful in more scientific applications. It can be used to input and output control pulses, output steady state logic levels and act as a controllable short interval timer, all under software control.

The eight peripheral slot connectors (0 to 7) simplify input and output for the Apple. Each one is connected to the computer's data, address and control buses, the power supply and the system drive clock. In addition, the address bus on the main board is partially encoded to give three low level pulses that are used to select the slot connectors and hence their attached

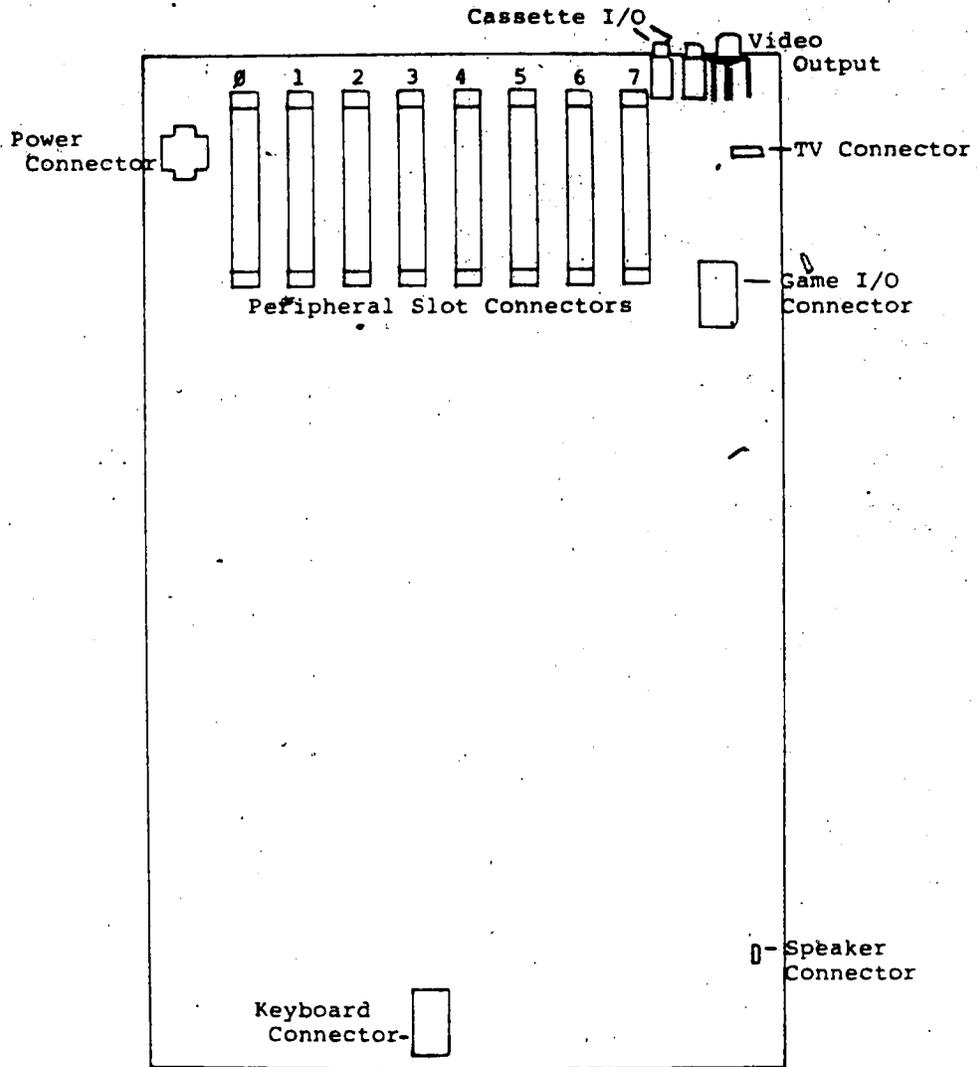


Figure 35. Input/Output connections on the Apple II+ main circuit board.

peripheral devices. The Apple has been commercially successful and there are a lot of reasonably priced peripheral devices available that can be plugged directly into the slot connectors.

The direct reader system has six of these eight slot connectors in use, as shown in Table 15.

Five of the six plugged in peripherals are commercial devices and are described below. The sixth is a custom built circuit to control the integration times of the array and is described in a separate section.

#### 2.1 16k Byte Memory Expansion Board

This uses the same memory addresses as the Apple monitor and BASIC language read only memory (ROM). This restricts its usefulness. It is intended to be used to store a language interpreter as an alternative to the Applesoft floating point BASIC in ROM. When loaded with Integer BASIC, it has, as part of that language set, a restricted form of assembler language that is useful for writing programs for machine code operation.

This extra memory can be used to store machine language programs and binary data. It was considered for this purpose but diskette storage was found to be more convenient.

Table 15. System use of the peripheral slot connectors of the Apple II+.

SLOT	PERIPHERAL DEVICE
0	16k memory expansion board
1	Printer interface board
2	-
3	12-bit analog to digital converter
4	I/O board
5	Integration timer circuit board
6	-
7	Disc operating system controller

## 2.2 The Printer Interface Board

This is a GRAPPLER + by Orange Micro and it is interfaced to an Epson MX80FT dot matrix printer. The combination can print out information up to 80 characters wide and also give a printed copy of any high resolution graphics display on the video monitor.

## 2.3 The 12-Bit Analog to Digital Converter

This is an AI13 analog input system from Interactive Structures Inc. It has 16 software selectable analog input channels, 8 software selectable voltage ranges and a conversion time of 20  $\mu$ s. On its lowest range (0 to 0.1 volts) the least significant bit (LSB) value is 0.024 mV, well below the 0.6 mV value for the 4-bit A/DC used with the AIM 65.

The AI13 is used in a mode that takes an externally generated high to low TTL transition as a trigger for conversion (the negative edge of the diode array RC1024S board's sampling pulse), and then generates an interrupt after conversion is complete.

Although the AI13 does not need a further preamplification stage for gain, it does require the analog inputs to be offset by means of a summing amplifier, in order to use its lower input voltage ranges. This is required to overcome the variation of the background level of the photodiode array with changes in integration time.

The amplifier shown in Figure 36 was built 6 times, once for each array. The operational amplifiers are LF351 from National Semiconductor Corporation and are of a similar type to the ones used previously. The A113 takes its power off the Apple power supply (+11.8 V, -12 V, +5 V). The preamplifiers are also powered by the Apple to avoid any accidental overload of the A113. The offset controllers are 10 turn precision wire wound potentiometers, equipped with turns counting dials. These were mounted on the side of the amplifier case to allow various offset voltages to be switched in quickly and reproducibly.

#### 2.4 The Input/Output Controller Board

This is the DI09 I/O board from Interactive Structures. The controller contains two 6522 Versatile Interface Adapter (VIA) integrated circuits and has some partial address decoding. Thus it has four 8 bit parallel I/O ports with 8 control lines.

Only one 6522 is used by the system. The lower 3 bits of port A (PA0 to PA2) are used as inputs to read the encoded identity of a start pulse and determine which array is about to be read out. This identification is required so that the computer can select the correct input analog channel of the A/DC and select the correct data storage addresses. The upper 4 bits of port A (PA4 to

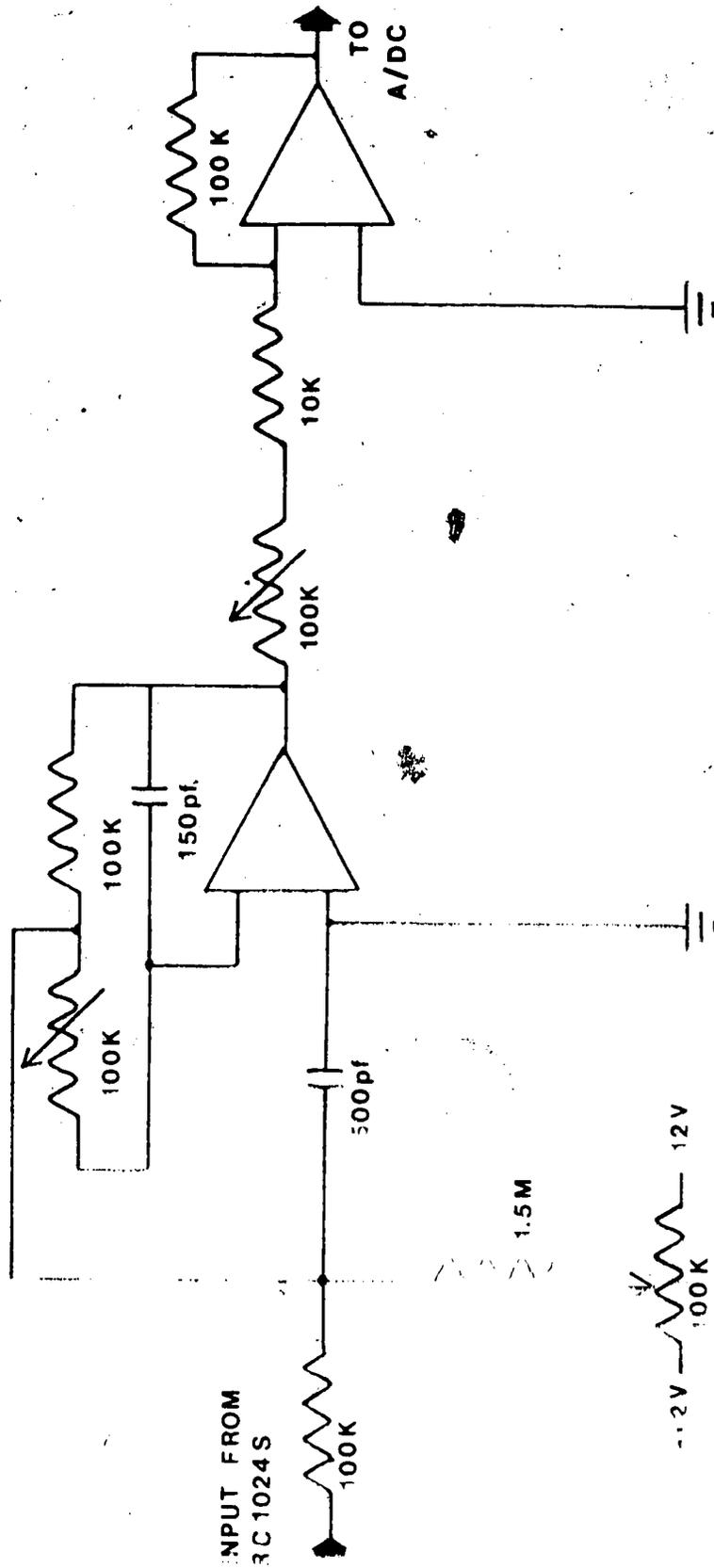


Figure 36. The preamplifier circuit for use with the A113 A/DC.

PA7) and all bits of port B (PB0 to PB7) are used as outputs to load a digital to analog converter. This allows any data in the system to be displayed on an oscilloscope or graphed by a chart recorder.

For data collection, the I/O controller board has to detect both the rising and falling edges of the start pulse of the array about to be read out. This is done through control line CA1.

### 2.5 The Disc Operating System Controller

This supports 2 disk drives that use 5 1/4 inch diameter floppy disks. Drive No. 1 is usually loaded with the direct reader operating system disk. Drive No. 2 is used for data storage disks.

It has become normal practice with Apple computers to put this controller in slot 6, however, in this system it has been moved to slot 7 to relieve crowding around the integration timer circuit board in slot 5.

## 3. The Integration Timer System

### 3.1 The Timing and Sequencing Principle

In order to allow measurement of a wide range of emission intensities, the individual photodiode arrays must have independently variable integration times. In order to be processed by a single data logging system, the readout times of the arrays must not clash.

The degree of variability allowed to the integration time has to be restricted so that both of the above conditions can be met.

A short time interval, long enough for 6 arrays to be read out with a little time to spare, is selected as the standard integration time increment. All integration times are controlled to be integer multiples of this increment. Each individual array is allocated a fixed portion of the standard time increment during which it may be read out. When the integration timers start running, each one starts at the beginning of its allocated portion of the standard time increment. As the integration times are an integer multiple of the standard increment, the readout for each array has to occur within its allocated portion although probably many standard increments later. This prevents readout clashes as the allocated portions for different arrays are separated by enough time for complete readout of an array. This is illustrated in figure 37.

The standard time increment is 0.1001  $\mu$ s made up of 31 pulses each of 3.129 ms. An array of 128 diodes takes 1 ms to be read out at a sampling rate of 10 kHz. Array 1 is allocated the first portion of the standard increment. Array 2 is allocated the portion beginning 17.647  $\mu$ s after the start of the standard

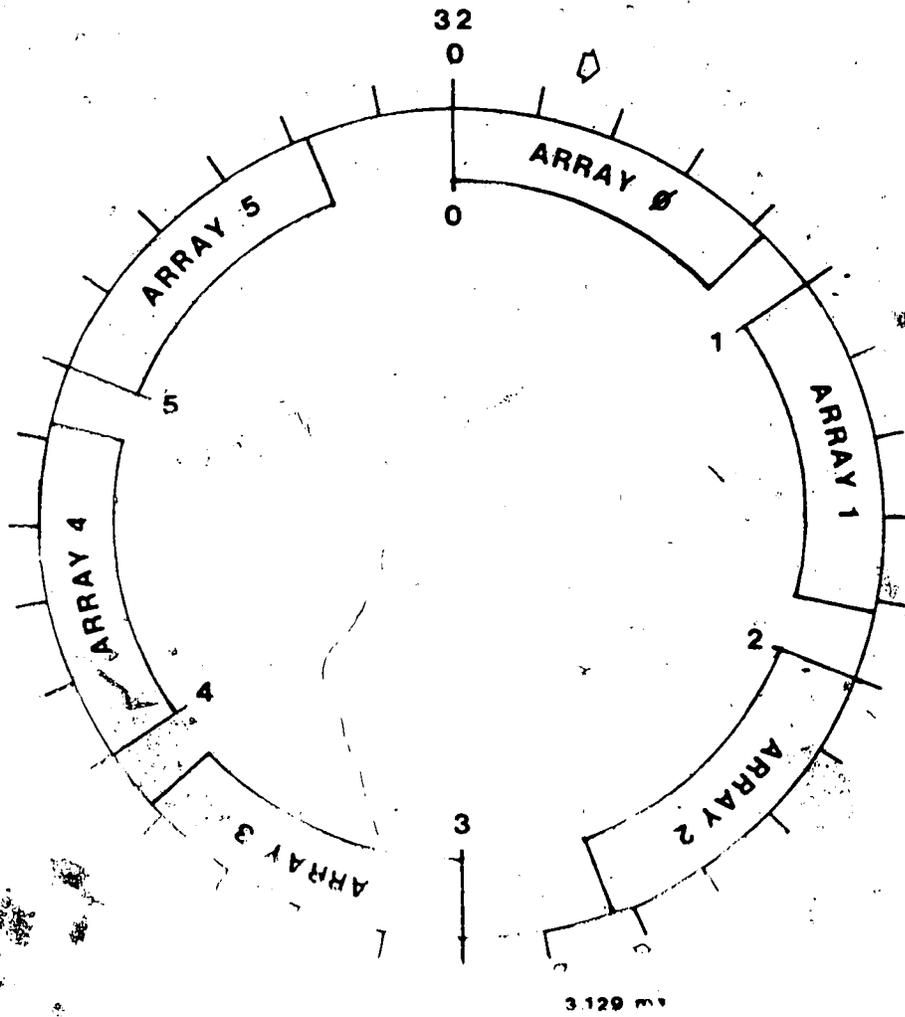


Figure 37. The integration timer cycle.

increment. Array 2 is allocated the portion starting 10 pulses after the start of the increment, and so on.

The integration times of each array have to be multiples of .1001 s. This also means that the minimum integration time is .1001 s, and this suggests that less prominent spectral lines may have to be used to analyze high concentrations of some elements to avoid saturation of the photodiode array.

It would be extremely difficult for the central processing unit of the computer to act as the timing device. It would have to run six counting loops and after it broke away from the counting loops to process the data from an array, it would have to correct the timing for the five arrays. It would have to loop for the first array, then loop for the second, and so on, until it had processed all six arrays.

The rate counter for the closed loop software would have the integration time as a series of time units that run independently of the central processing unit. The central processing unit would have to wait until it responds to the timing unit. The central processing unit would have to wait until it has processed one of the arrays and then it would have to process the corresponding data for the other arrays.

The rate counter

### 3.2 Design and Construction of the Timing Device

The timer system and its associated integrated circuits were assembled on an Apple peripheral prototyping printed circuit board. The logic diagram for this assembly is shown in Figure 38.

The primary oscillator of the Apple is a 14.31818 MHz quartz crystal. This frequency is reduced to 1.023 MHz to clock the central processing unit and this same reduced frequency is also made available at the peripheral slot connectors.

The heart of the integration timing system consists of four 8253 integrated circuit chips. Each of these has three 16-bit programmable down counters that can run independently of each other in any one of six modes and supplies the 12 counters necessary to run the system.

The 12 counters are utilized as follows:

1. One is used to reduce the time base clock frequency by a factor of 3,200 (to give a period of 3.129 ms) and this is used to drive the other eleven counters.
2. Five are used to control the gating of five of the integration counters to delay the start of their counting cycles by fixed amounts of time.
3. Six act as the actual integration timers. These are loaded with the integration times for each individual array as selected by the operator of the

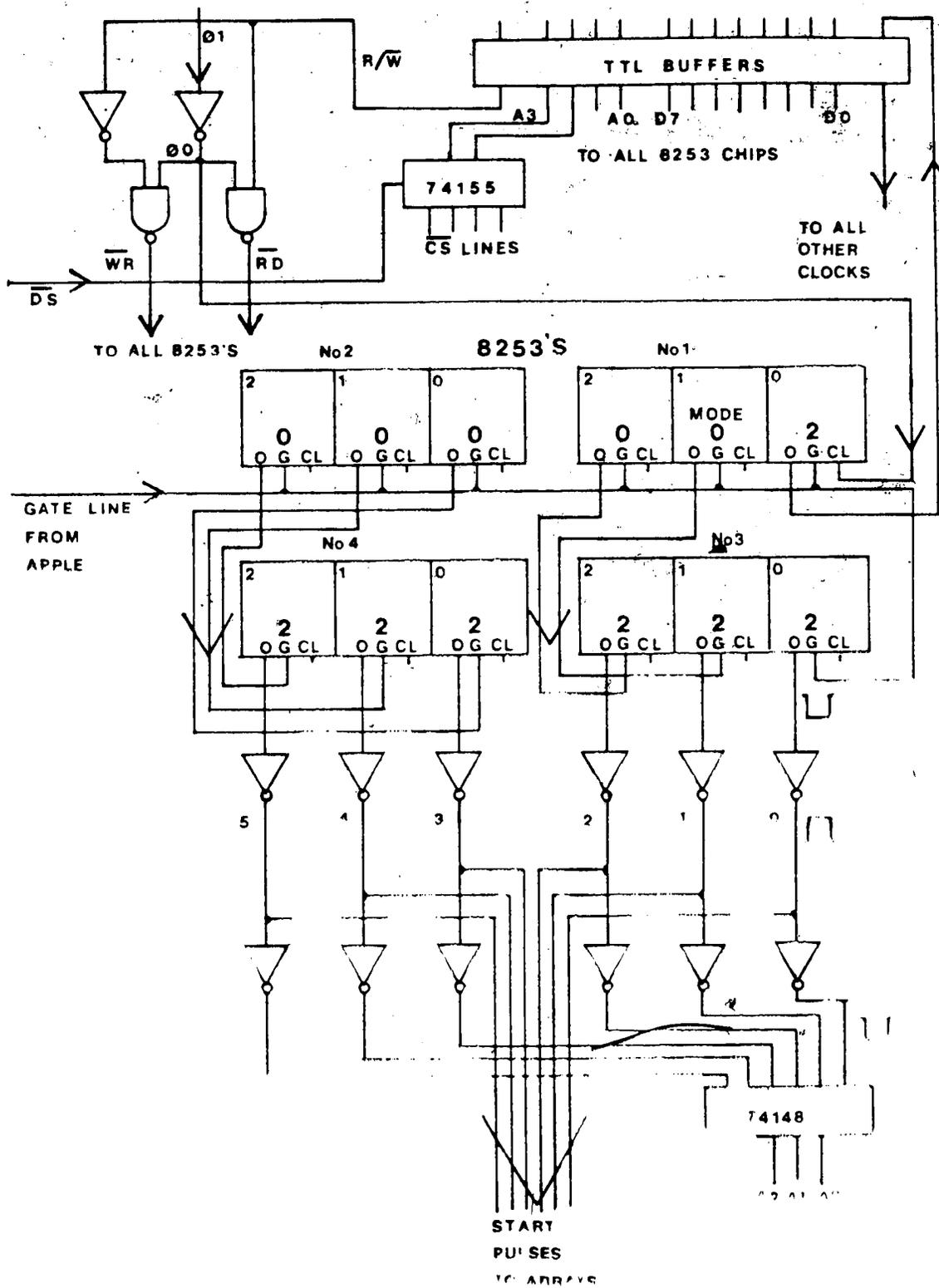


Figure 38 The integration time circuit logic

The power supply for the Apple has only 500 mA available at 5 V for all the eight peripheral slot connectors. As the four 8253 integrated circuits alone draw 560 mA the timer circuitry was driven by an auxiliary power supply.

The data bus and part of the address bus of the microcomputer have to go to all four 8253 chips. In order to avoid fan-out problems, the bus lines and the READ/WRITE control line were first buffered through 74125 tri-state buffers.

The circuit requires the  $\phi 0$  signal from the computer. This is the phase of the computer clock signal that goes high for data transfer. Because this signal has considerable fan-out on the Apple main board, it was recreated for the timer circuit by inverting its complement  $\phi 1$ .

For an added complication, the 8253 chips are not designed for use with the 6502 microprocessor that drives the Apple. They are designed for use with Intel's 8080 microprocessor. The essential difference between the two is that the 8080 has separate read and write control lines, while the 6502 uses a single line for both read and write control. When this line is high and  $\phi 0$  is high, the 6502 reads data. When the line is low and  $\phi 0$  high, the 6502 writes (outputs) data. A special interface has been

designed by V. Karanassios [48] to allow the 8253 and similar Intel chips to be used on 6502 based equipment and this was incorporated into the circuit.

Because the data bus was buffered through one way tri-states, the status of the count in progress could not be read out through the data bus. This does not matter as the timer output pins carry the end of count signals.

### 3.3 Addressing the Counters

The counters within the 8253 chips have to be individually programmed and this requires that they be individually addressed. The circuit board runs in slot 5 which has the dedicated address \$C0D0 to \$C0DF (\$ = hexadecimal symbol). When any of these 16 addresses is referenced a control line at the slot interface goes low for 500 ns. This is called the  $\overline{DS}$  (Device Select) pulse for that slot.

Consider the last hexadecimal digit of these 16 addresses expanded to its four binary address lines A3, A2, A1 and A0. Address lines A3 and A2 are fed to a 2 line to 4 line decoder (74155) which is activated by the  $\overline{DS}$  pulse. The four outputs from the 74155 are used as  $\overline{CS}$  (chip select) pulses and are fed individually to the four 8253 chips. Thus the particular chip being addressed is controlled by the values of A3 and A2. The A1 and A0 address lines go to all 8253 chips where they are used to

address the individual counters or to signify the transfer of control information (mode word). The full address list for write instructions to the system is given in Table 16.

In order to synchronize the start of the counting operations, the counters are inactivated during the data loading process. This is done by holding the gates of the frequency reduction and delay counters low (disable) with a software controlled logic level through the Apple game I/O connector. When all the counters are loaded the logic level is software switched to high, the gates are opened (enabled) and the count operations commence.

The timing diagrams for the counting processes are given in Figure 39.

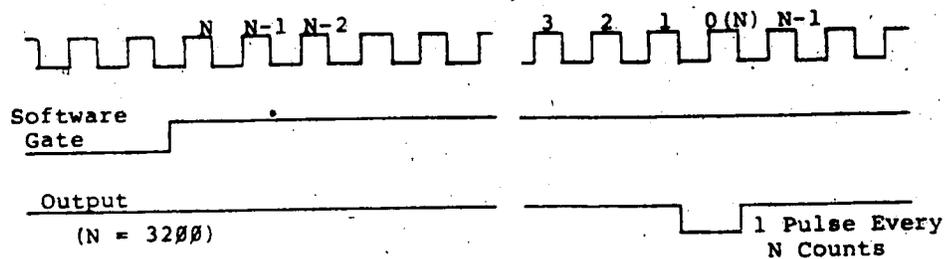
Counter 0 on 8253 #1 runs in mode 2 as a frequency reducer. It is loaded with a count for 3,200 and clocked by the 1.023 MHz Apple drive frequency. The output is normally high but every 3,200 clock cycles or 3.129 ms it goes low for 1  $\mu$ s. The reduced frequency output signal is buffered through a 74125 tri-state and then is fed to the other eleven counters in the system.

Counters 1 and 2 on 8253 #1 and all three counters on 8253 #2 are run in mode 0 as interrupt timers. The outputs go low as the counter register is loaded. When the count starts the output remains low until full count occurs, whereupon it goes high and stays high until the

Table 16. The address list for loading the integration timer system.

ADDRESS (HEX CODE)	8253 ADDRESSED	EFFECT OF WRITE INSTRUCTION
\$C0D0	1	LOAD COUNTER #0
\$C0D1	1	LOAD COUNTER #1
\$C0D2	1	LOAD COUNTER #2
\$C0D3	1	WRITE MODE WORD
\$C0D4	2	LOAD COUNTER #0
\$C0D5	2	LOAD COUNTER #1
\$C0D6	2	LOAD COUNTER #2
\$C0D7	2	WRITE MODE WORD
\$C0D8	3	LOAD COUNTER #0
\$C0D9	3	LOAD COUNTER #1
\$C0DA	3	LOAD COUNTER #2
\$C0DB	3	WRITE MODE WORD
\$C0DC	4	LOAD COUNTER #0
\$C0DD	4	LOAD COUNTER #1
\$C0DE	4	LOAD COUNTER #2
\$C0DF	4	WRITE MODE WORD

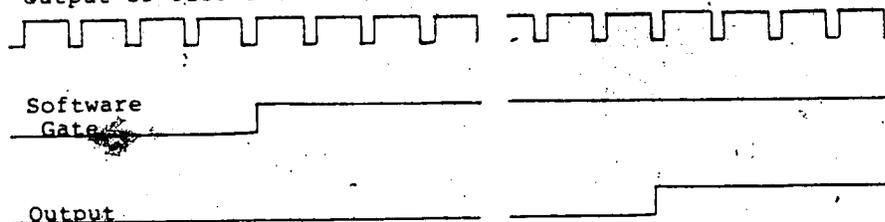
8253-1 Counter  $\emptyset$ . Frequency Reducer. Mode 2. Computer Clock



DELAY COUNTERS

8253-1 Counters 1 + 2, 8253-2 Counters,  $\emptyset$ , 1, 2, MODE  $\emptyset$

Output of 8253-1 Clock  $\emptyset$  (Period 3.129 ms)



START PULSE TIMERS

8253-3 and 8253-4, all counters

Output of 8253-1 Clock  $\emptyset$

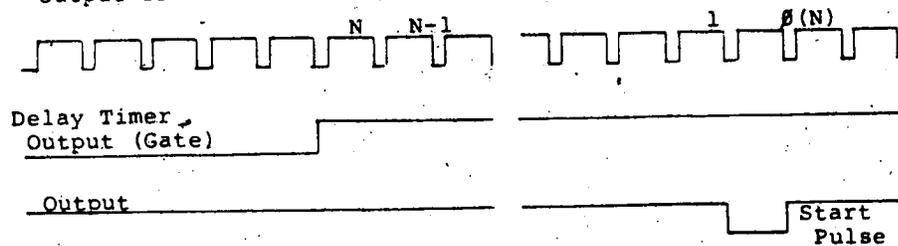


Figure 39.

Timing diagrams for the 8253 software programmable counters.

count register is reloaded. As this only occurs when all the counters are being loaded, once the output has gone high it stays high for the duration of all of the counting operations. The outputs of these 5 counters are used to gate 5 of the integration timer counters. They are loaded with sufficient counts to hold their outputs low for the delay intervals required to sequence the integration timers.

The six counters on 8253 #3 and #4 run in mode 2 as frequency reducers. They are loaded with counts that generate pulses at periods corresponding to the required integration times. At the completion of each count a negative pulse 3.129 ms wide is generated as a start pulse. As the counters are 16-bit, they can count up to 65,536 pulses of 3.129 ms and this gives a maximum integration time of 205 s.

#### 3.4 Further Processing of the Start Pulse

The negative start pulse is inverted to a positive one and fed out to the appropriate diode array RC1024S control board. It opens the gate for the control board oscillator and also clocks the onboard flip-flop (Figure 18) so that its output goes high.

The pulse is also reinverted and sent to a 74148 priority encoder. This detects which start pulse has occurred and translates this information into a code that

is the binary equivalent of the number identifying the array to be read out. This code is fed to the Apple computer through the PA0 to PA2, inputs on the DI09 input/output controller board.

The computer program for data acquisition requires that the identity of the array be generated in straight binary. Reference to the truth table (Table 17) indicates that if the start pulse for diode array 0 were fed to input 0 on the 74148, it would generate binary 1,1,1 at the outputs A2, A1, A0. This is the 1's complement of the 0,0,0 required. The outputs from the 74148, could be inverted but the printed circuit cannot hold another integrated circuit chip. The correct coding at the outputs is obtained by connecting reinverted start pulse 0 to input 7 on the 74148, 1 to 6, etc.

The input enable is grounded so that the 74148 is always operating when the power is on. For most of the integration period the outputs will be high but this is immaterial as the computer only samples them after a start pulse has been received.

The integrated circuit chip layout for the integration timer board is given in Figure 40. Sockets A and B, are wired in parallel. A plug into A transfers the generated start pulses to the leads to the diode array control boards. It also brings in the OR'd sampling



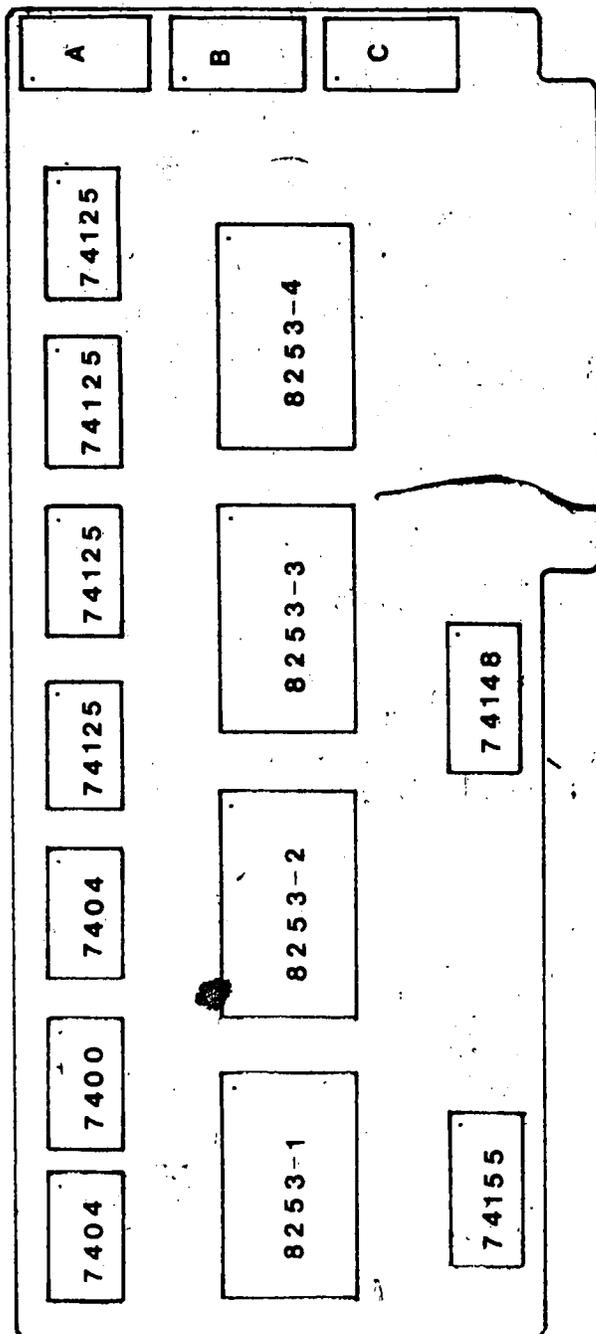


Figure 40. Chip layout of the integration timer circuit board.

pulses and start pulses back from the array control boards (discussed in section 4 of this chapter).

A plug into B transfers the start pulses to an LED display (discussed in section 5 of this chapter). This plug also acts as a connector for the transfer of the CR'd sampling pulses to the trigger of the analog to digital converter (section 2.3 of this chapter) and of the OR'd start pulses to control line CA1 on the DI09 input/output controller board. Socket C is connected to the A2, A1, A0 outputs of the 74148 priority encoder. A plug in C carries these lines to the PA0 to PA2 inputs on the DI09

#### 4. Timing Signals Required by the Computer

The Apple computer uses the timing signals from the array board differently to the way they were used by the AIM 65 for a single array. The computer must identify the array about to be read out so that it can switch the data to the correct analog channel and set up the correct storage addresses for the data.

During data acquisition the integration timer system runs independently of the microprocessor. The first indication that an array is about to be read out is the leading positive edge of the start pulse (see Figure 17). This clocks the 7414 flip flop on the PC10249 board (Figure 18) setting the output high. The output of this

the boards for all 6 arrays are logically OR'd together and the resulting single line fed to the computer through control line CA1 on the I/O board. The computer reacts to this low to high transition, reads the identity of the array from the 74148, and sets up the A/DC input channel and the correct addresses in the data storage program. It has less than 200  $\mu$ s to do this before the Q output is cleared to low by the  $\phi$ 2 ODD pulse.

The sampling pulses for all of the arrays are likewise logically OR'd together and the resulting single line fed as a trigger to the A/DC. As with the AIM, the first diode read out corresponds to the first sampling pulse received after the Q output of the flip-flop is cleared to low. The diagram for the circuit to OR the signals is shown in Figure 41.

The computer detects the edges of the OR'd start pulses returned from the array boards, not those of the pulses generated by the timer circuit board. Consequently, it does not matter that the latter are active for 3.120 ms. They will be inactive well before the next start pulse is generated.

With the single array system the sampling pulse was fed to the A/DC and the conversion completed signal was used by the AIM as a cue to read the data values. The AIM operates differently. The A/DC operates under the

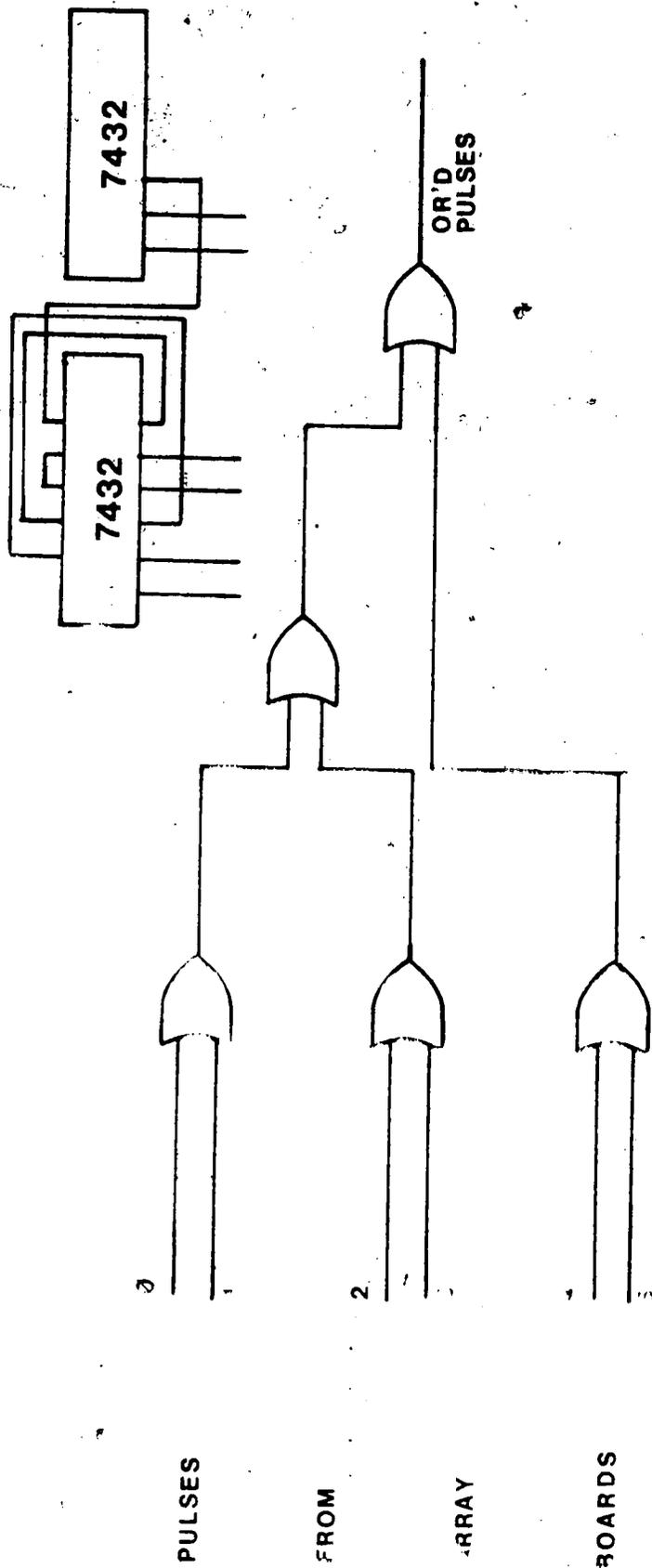


Figure 41. Logic to OR the start or sample pulses of all six arrays.

control of the computer which has to supply the identity of the analog channel and the A/DC range setting. The actual conversion occurs after a negative edge trigger (the sampling pulse) and the computer polls the high byte address of the A/DC for the signal that indicates the completion of the conversion before reading the data values. This slightly lengthens the time to read out a single diode but the length of the diode readout loop still remains less than the 100  $\mu$ s limit required by a 10 kHz readout rate.

## 5. Auxiliary Circuits

### 5.1. A Start Pulse Indicator

After a change has been made in the analyte aspirating into the plasma nebulizer, all of the diode arrays must be cleared by completing their current integration period before valid data can be taken. If this is not done the data would be spurious. It is very easy to lose track of the integration state of 6 arrays and excessive delay wastes time. A start pulse indicator was built as an operating aid to keep track of the clearing arrays. The circuit diagram is shown in Figure 42.

As a start pulse occurs, it clocks a 7474 flip-flop and sends its Q output high and the complementary  $\bar{Q}$  output

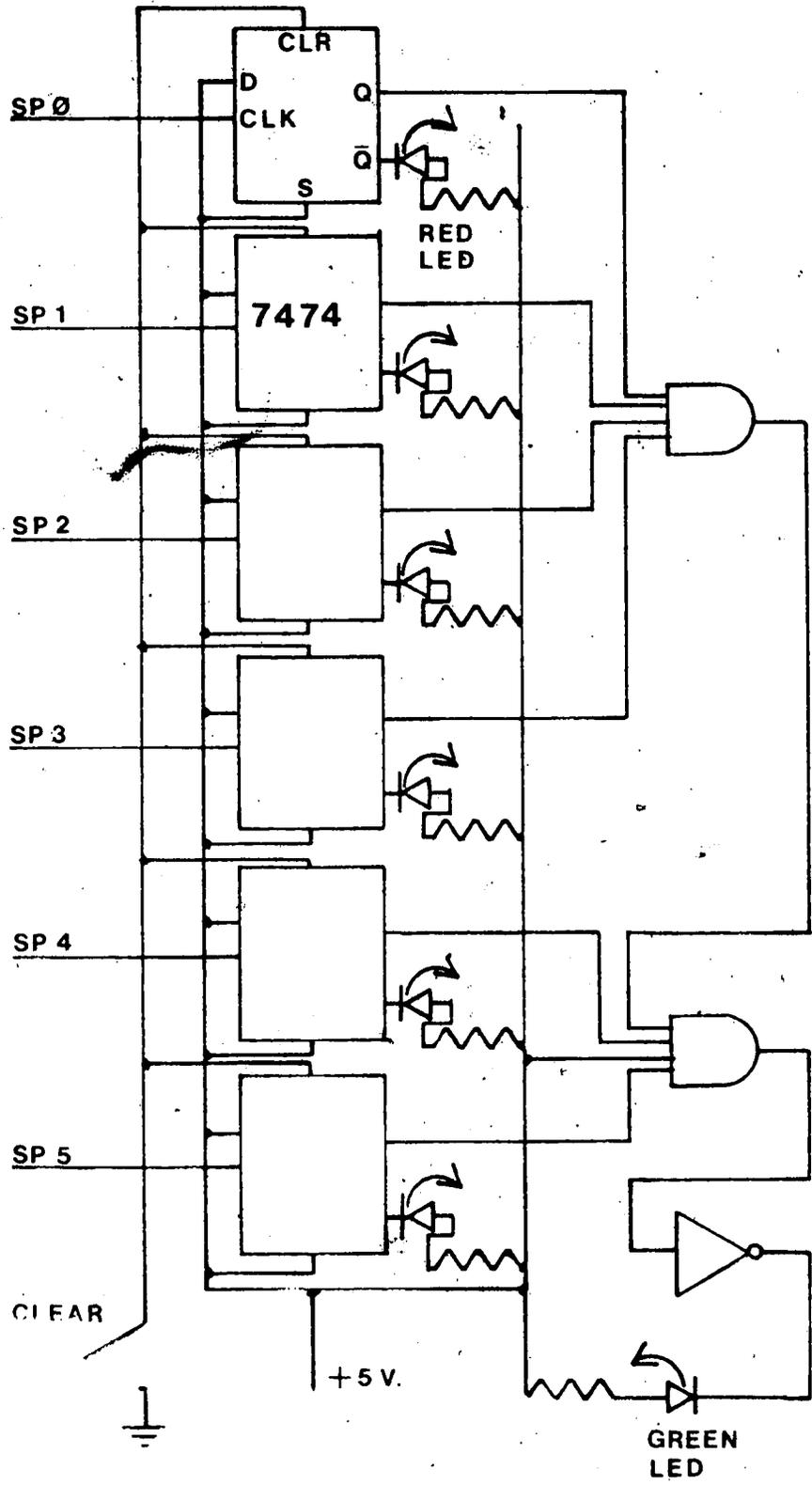


Figure 42. The start pulse indicator circuit.

low. The low  $\bar{Q}$  forward biases a red LED so that it lights up.

The Q outputs for all 6 flip-flops are combined through AND gates so that a high logic level state occurs after all the arrays have received at least one start pulse. This high level is inverted to a low level that forward biases a green LED causing it to light up.

When the operator has made an analyte change and is satisfied that the plasma emission has restabilized, he presses a button that clears all of the flip-flops. Their  $\bar{Q}$  outputs go high and all the LEDs go out. As the arrays complete their next integration cycle, their corresponding red LEDs light and when all reds are lit the green also lights as a signal to the operator to start the data acquisition process.

## 5.2 Output to a Chart Recorder or Oscilloscope

It is very useful to be able to display a digitized, recorded spectrum on an analog device such as a chart recorder or an oscilloscope. This requires reconversion of the digitized signal to an analog one through a digital to analog converter (D/AC). The circuit diagram is shown in Figure 43.

The computer has an 8-bit data bus and so must process and store 12-bit data in two bytes. When the data fed to the D/AC is to be changed, it must be changed at

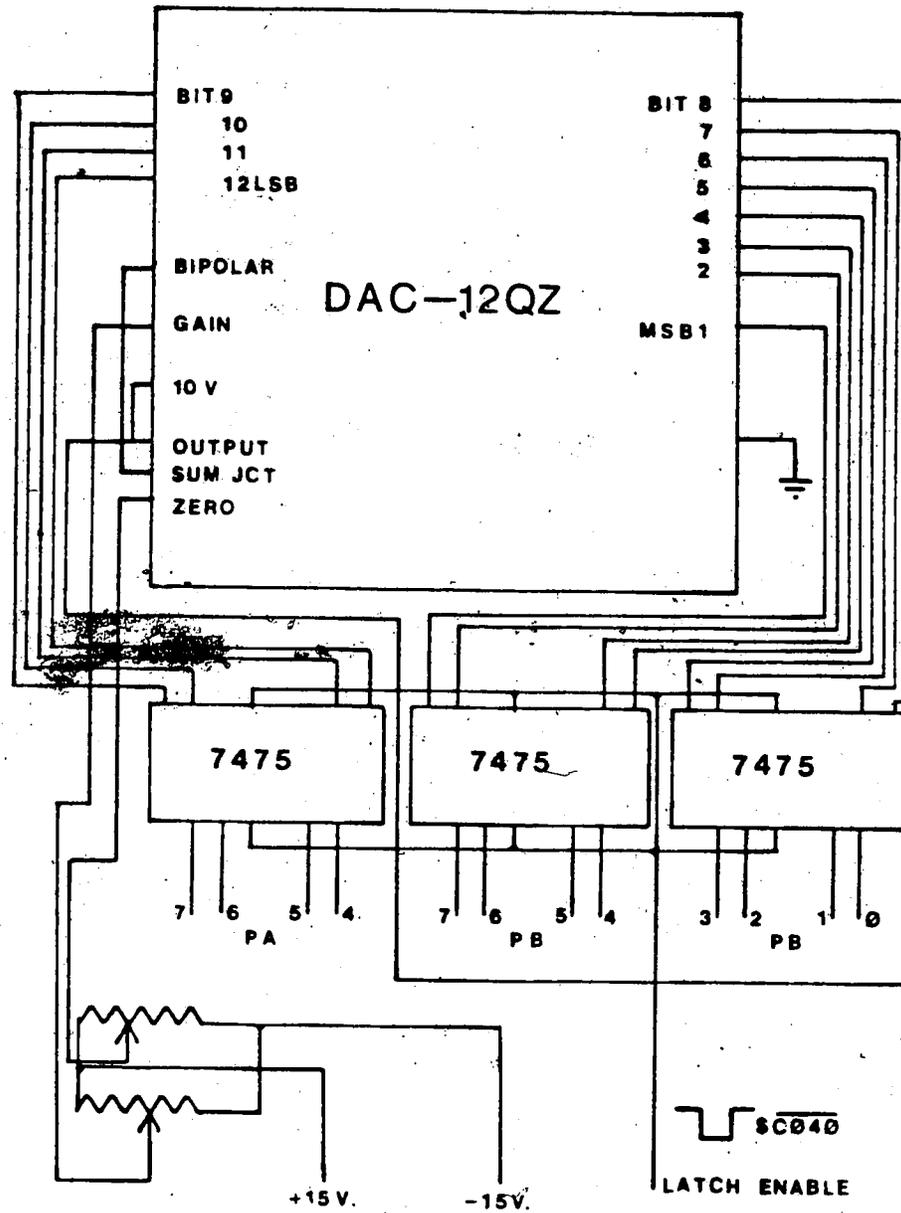


Figure 43. The digital to analog conversion circuit.

all D/AC inputs simultaneously. This is achieved by loading the output from the computer onto the inputs of 7475 latches. The latches are then all enabled simultaneously so that the data at their inputs is transferred to their outputs and on to the D/AC inputs.

The digital signal is put out through the PB0 to PB7 and PA4 to PA7 ports of the D109 input/output controller which are dedicated to this task. (The lower ports PA2 to PA0 are dedicated to the input of the array identity code.) This means that both bytes of the data values have to be software shifted 4 bits higher in the data buffer prior to loading the D/AC.

A diagram showing the interrelationship of the circuitry built external to the direct reader light proof box is given in Figure 44.

Inside the light proof box, all digital and analog signals are carried as far as is practical by coaxial cable to prevent cross-talk. Outside the box, the analog signals are carried by coaxial cable as far as the preamplifier. Digital signals are carried by VARI-TWIST flat cable between the light proof box and the Apple computer.



## 6. The Computer Operational Plan

The Apple computer uses 2 byte or 16-bit addressing and so can reference any of 65,536 memory locations. This may seem like a lot but a considerable portion of it is already committed to operating systems and language interpretation. That portion still available is not sufficient to hold all of the necessary programs and store the acquired data from 6 arrays.

Because of this memory shortage, a system is used that makes extensive use of disk storage. This is based on the Disk Operating System (DOS) of the computer and the ease of inclusion of DOS commands within a BASIC program.

A master program, written in BASIC, displays a menu on the video monitor and allows the operator to call up other BASIC programs from the disk. These secondary programs control the various operations required, calling up other programs written in BASIC or machine code as needed. For high speed operation, data logging and control functions are carried out by machine language programs with BASIC used to communicate with the operator.

### 6.1 Organization of the Apple Memory Space

The memory space allocation is shown in block form in Table 18. With disk operating system booted, about half of the memory addresses are allocated to specific uses.

Table 18. Memory space utilization of the Apple II+.

HEX FROM	ADDRESS TO	MEMORY FUNCTION	
D000	FFFF	BASIC AND MONITOR	ROM
C000	CFFF	I/O RESERVED SPACE	
9600	BFFF	D.O.S. RESERVED SPACE	RAM
7300	95FF	BINARY STORAGE AND MACHINE CODE PROGRAMMING SPACE	RAM
4000	72FF	BASIC PROGRAMMING SPACE	RAM
2000	3FFF	HIGH RESOLUTION GRAPHICS PAGE 1 STORAGE	
0800	1FFF		
0400	07FF	VIDEO SCREEN TEXT SPACE	RAM
03F0	03FF	VECTOR STORAGE SPACE	RAM
0300	03EF	AVAILABLE MACHINE CODE SPACE	RAM
0200	02FF	KEYBOARD INPUT BUFFER	RAM
0100	01FF	SYSTEM STACK	RAM
0000	00FF	ZERO PAGE	RAM

In order to run both BASIC and machine code programs a bank of addresses had to be reserved for machine code and binary storage. The memory addresses between \$72FF and \$95FF were reserved by starting all BASIC programs with the statement HIMEM:29439 (\$72FF in hexadecimal). This prevents BASIC use of the addresses above \$72FF. \$9600 is the lowest address used by the DOS.

The machine code and binary storage memory was subdivided as shown in Table 19.

Whenever a machine code program is called from disk, it is loaded into the memory space that begins at \$9200. The scratch pad memory addresses are individually allocated as listed in Appendix 5. Operating parameters are called for by BASIC programs and then stored in the scratch pad area using the BASIC POKE statement. They are then read and utilized by machine code programs.

The binary storage memory accommodates 4 files. Newly acquired data for all arrays (768 diodes) is stored as received in the buffer file in real time. It can then be relocated, if necessary, to the background raw data storage file. The analyte and background means files are used to store the mean (signal averaged) data values calculated through a BASIC program from the accumulated values in the other files. The availability of several storage files in RAM allows background subtraction and other spectrum stripping techniques to be used.

Table 19. Utilization of protected machine code and binary data memory space.

HEX FROM	ADDRESS TO	MEMORY FUNCTION
9200	95FF	MACHINE CODE PROGRAMMING SPACE
8900	91FF	BACKGROUND RAW DATE FILE
8000	88FF	INPUT BUFFER (DATA FILE)
7F01	7FFF	SCRATCH PAD MEMORY SPACE
7900	7EFF	ANALYTE MEANS FILE
7300	78FF	BACKGROUND MEANS FILE

## 6.2 Programming

When the computer is booted with a disk loaded with the direct reader operating system programs, the main menu, shown in Figure 45, appears on the video monitor.

The various options listed can be called up through the master program by entering the selection number, or called directly from the disk by the DOS command RUNSEL followed by the number.

All of the programming techniques are described and the programs listed in Appendix 6. Their general functions are briefly described here.

### 6.2.1 1. Define the Integration Times

The program asks for the integration time for each of the 6 arrays. The entered values are corrected to valid values and entered into scratch pad addresses. The machine code part of this program then loads the necessary count values into the 8253 counters on the integration timer circuit board and starts the integration cycles.

The RESET key on the Apple cancels the operation of the integration timer board but does not affect the data stored in scratch pad memory. To save time, a quick reload option (no data entry required) is included in this program.

1. DEFINE THE INTEGRATION TIMES
2. ACQUIRE SETS OF DATA POINTS
3. SET UP A SHORT INTEGRATION TIME  
FOR A SINGLE ARRAY
4. SUBTRACT BACKGROUND AND  
STORE AS MEANS
5. DISPLAY GRAPHICALLY ON THIS SCREEN
6. SAVE DATA ON DISKETTE
7. DISPLAY ON AN OSCILLOSCOPE
8. OUTPUT TO CHART RECORDER
9. DISPLAY VALUES ON THIS SCREEN
10. SMOOTH (PAIR AVERAGE) THE  
INPUT BUFFER
11. OBTAIN DATA VALUES FROM A FILE
12. CALCULATE CONCENTRATIONS

ENTER INSTRUCTION # AND PRESS RETURN

Figure 45. The direct reader operating system main menu.

### 6.2.2 2. Acquire Sets of Data Points

This program requires two input parameters for every array. These are the gain code to set the range for the A113 analog to digital converter and the number of replicate runs to be taken for signal averaging. Again there is a quick load option (no data entry) but in this case it is to keep the parameters constant for a series of analytical runs. The machine code portion of the program is rather complicated as it involves control of the A/DC and storage address selection as well as data logging.

### 6.2.3 3. Set Up a Short Integration Time for a Single Array

This is a variation of selection 1 and is used to control the integration time of a single array during the setting up and tuning of the array system. It allows integration times as short as 0.018 s for a single array while the other 5 have an integration time of 205 s. It can also be used to collect data values for a very intense spectral emission that would saturate the array if run at the 0.1001 s minimum integration time allowed by selection 1.

### 6.2.4 4. Subtract Background and Store as Means

This program subtracts one set of spectral values from another; if necessary, it calculates mean values

Sheet 11 - Worksheet Data in any form or as recalculated  
values. It will also be in the computer's RAM or on a hard  
disk. In any program, it is almost always possible to  
retrieve a copy of the data.

#### Formulas Applied to the Screen

The formulas applied to the screen are those that are  
applied to the data. The formulas are applied to the  
data in the same way as the data is applied to the  
screen. The formulas are applied to the data in the  
same way as the data is applied to the screen. The  
formulas are applied to the data in the same way as  
the data is applied to the screen. The formulas are  
applied to the data in the same way as the data is  
applied to the screen.

## 6.1.8 Output to a Star Recorder.

The output of the input buffer is

the same as the output of the

input buffer.

Apply the same method to

the output of the input buffer.

The output of the input buffer

is the same as the output of

the input buffer.

The output of the input buffer

is the same as the output of

the input buffer.

The output of

is

calculate the background to suit the interferences present on the array.

### 12. Calculate Concentrations

The program allows the calculation of the concentrations of several analytes from their peak heights by linear interpolation of the values for calibration standards.

In addition to the direct reader system programs, two more have been written to assist in the placement of arrays. These are on a separate disk which also contains a set of text files compiled from the table of prominent lines in the ICF published by King, Peterson and Fassel [12]. The program ALPAYTEL allows the compilation of a text file containing the prominent lines of selected elements from up to three periodic tables. These are sorted into columns by number of lines, first wavelength, and then by element symbol. The program LINEPRINTER prints out a list of the lines along the first column of the periodic table. The program LINEPRINTER also prints out a list of the lines along the first column of the periodic table. The program LINEPRINTER also prints out a list of the lines along the first column of the periodic table.

7. Engineering Considerations

The operation of six arrays in a confined space required careful planning of the services to each array. Because the positions of the arrays had to be adjustable over a wide range of distance along the focal plane of the direct reader, all service lines had to be flexibly arranged so that they could be kept in an orderly fashion. Services had to be obtained from available sources and supplied through distribution systems so that all of the arrays received the same amount of service.

7.1 Cooling Considerations

The photodiode arrays require cooling to reduce the integrated dark current. Two coolers had been used for the single array system. These coolers consisted of heat pumps (Figure 8) and large cans (Figure 9). The heat pumps were more effective in cooling the arrays and would have suffered from the same problems as the other system. The large cans were used because they were not as expensive as the heat pumps and they could be used for other purposes. It was found that the heat pumps were more effective in cooling the arrays and would have suffered from the same problems as the other system. The large cans were used because they were not as expensive as the heat pumps and they could be used for other purposes. It was found that the heat pumps were more effective in cooling the arrays and would have suffered from the same problems as the other system.

The design of the coolers based on the miniature Peltier heat pumps was re-examined. Redesign allowed the number of pumps to be doubled, from 2 to 4, and also increased their efficiency by improving the heat transfer from the array to the heat pumps. During trials it was found that this arrangement would cool the back of the array by  $34^{\circ}\text{C}$  below the temperature of the tap water supply ( $14^{\circ}\text{C}$  in February) to  $-21^{\circ}\text{C}$  and this was considered to be adequate. If the temperature should need further reduction, at some future date, the cooling water could be replaced by a cooling fluid supplied from a refrigeration type of chiller.

The four Peltier heat pumps for each array cooling system were electrically connected in series and drew 2 A at 6 V. Sufficient power supplies were available to supply the 12 A required.

The cooling water supplied to the hot side of the Peltiers had to remove 6.24 watts of pumped heat and 12 watts of  $I^2R$  heat from each array cooling system. These 18.24 watts are equivalent to 4.4 gm calories per second. This would require a water flow rate of at least 5 ml/s as efficient cooling requires that the water temperature rise be kept as low as possible ( $1^{\circ}\text{C}$ ). The temperature rise with each cooling system would cause too much heating if all of the pumps were connected in

series with a water throughput of 30 ml/s. Consequently, the water supplied to the coolers had to be drawn in parallel off a manifold. All water hoses were cut to the same length in an attempt to equalize flow rates.

The dry nitrogen necessary to prevent fogging of the cooled array was fed to the six arrays through a manifold. Its pressure was controlled within the range of 8-15 cm of water head pressure.

## 7.2 Power Supplies

The power supplies for the 6 array control boards and for the Peltier coolers were distributed through sets of sockets fitted with irreversible plugs to maintain correct polarity. The general layout of the services within the direct reader light proof box is shown in Figure 46. Details of the power supplies are given in Appendix 7.

## 7.3 Location of the Plasma Power Unit

The RF generator for the ICP is cooled by a flow of water. Vibrations from the fan were picked up by the direct reader light proof box during the single array trial. The effect of the vibration on the stability of the system could be observed by watching the oscilloscope pattern of the array readout at short integration times. During an eight hour run of the system the vibration was sufficient to

Nitrogen distribution      D Water manifolds  
 Helium power distribution   E Analog plugs  
 Array power distribution   F Digital plug

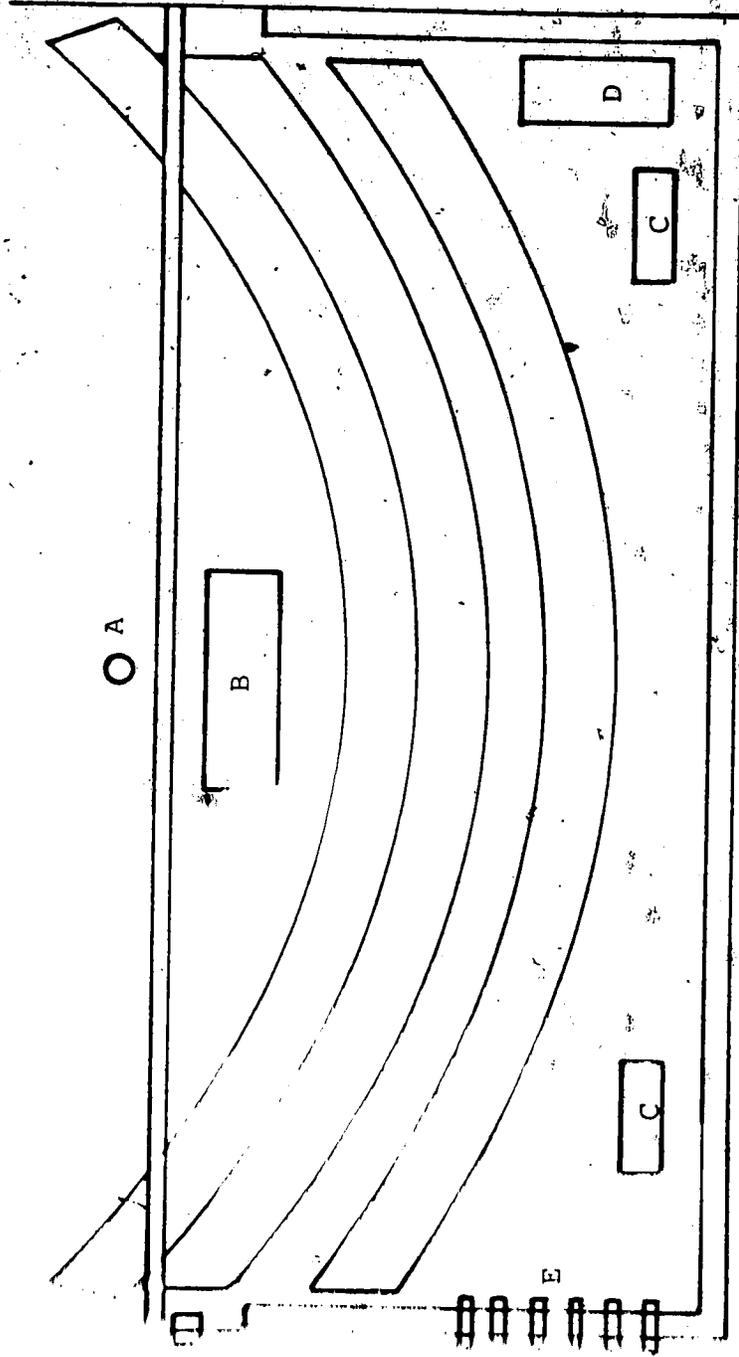


Figure 46. The layout of the services in the focal plane area of the six array system.

For the multi-array system, the power unit was moved out of the room, taking advantage of the 13 ft long cable connector between the power supply and the matching network at the plasma head. This effectively solved the vibration problem.

This completes the description of the construction of the utility is described.

## CHAPTER VI

### USE OF THE PHOTODIODE ARRAY DIRECT READER

The photodiode array direct reader has to be evaluated as a spectrometer.

The data presented in Chapter IV have shown that, when allowance is made for the instrumental effects caused by the diffraction grating, the photodiode array spectral windows have detection limits equivalent to those obtained with a photomultiplier tube system. This chapter describes how the spectral windows obtained with the diode array system can be applied to the problems associated with photomultiplier tube systems described in Chapter I. Where a background correction is applicable it is applied. Where this is not possible, due to grating interference, an approach to correction is made. Where correction is not possible, the length of the side arm of a interferometer is varied to compensate for the grating interference.

#### 1. Introduction

The reader is reminded that the calculations for the photodiode array system are based on the analysis of the spectral windows obtained from the grating. The reader is reminded that the calculations for the photomultiplier tube system are based on the analysis of the spectral windows obtained from the grating.

In order to demonstrate the versatility of the system, the direct reader is set up and used to solve an analytical problem.

Spectral Resolution

One of the criteria for evaluating a spectrometer is its ability to resolve two closely spaced lines. The photodiode arrays record spectral measurements at 0.014 intervals. A study was made of the resolution of two lines of approximately equal intensity separated by a wavelength of about 10 nm.

The direct reader will not resolve the 670.76 nm and 671.81 nm lines. The resolution of the direct reader is about 10 nm. The resolution of the photodiode array is about 0.014 nm. The resolution of the photodiode array is about 0.014 nm. The resolution of the photodiode array is about 0.014 nm.

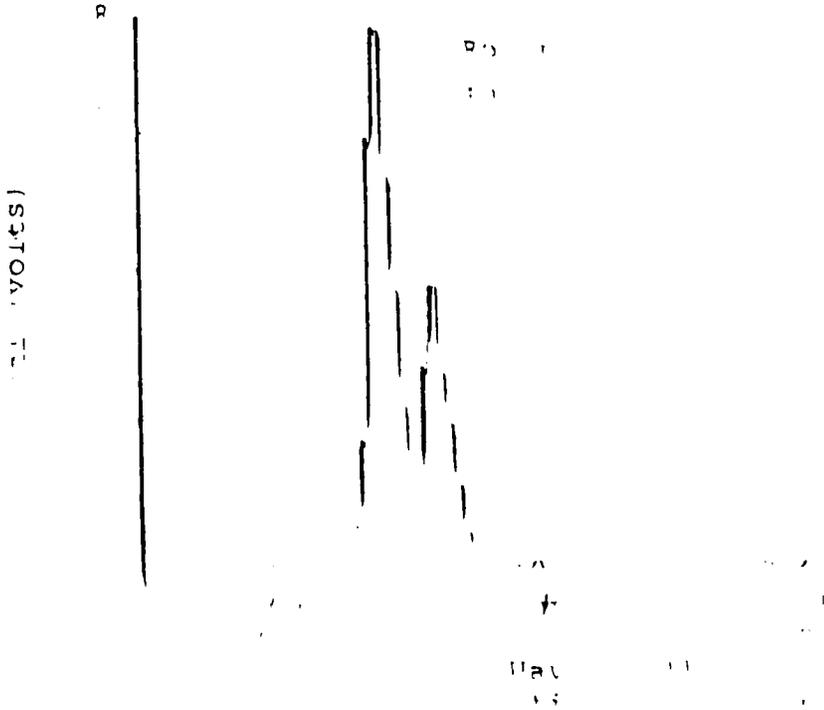
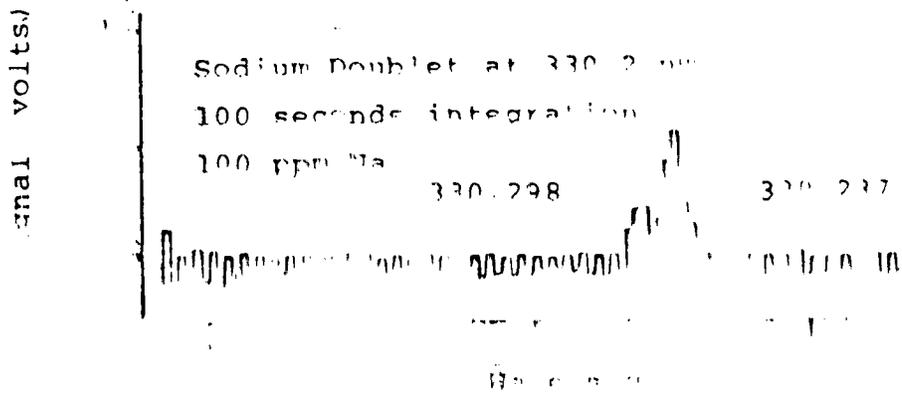
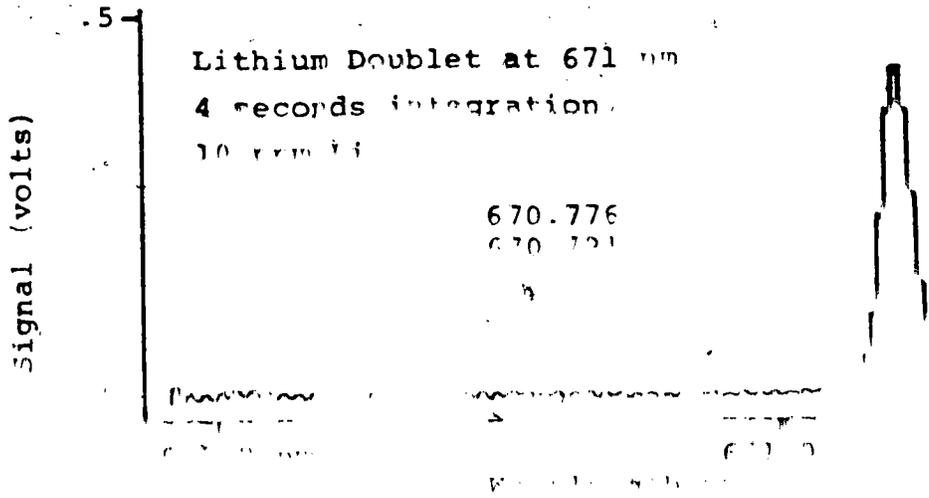
The resolution of the photodiode array is about 0.014 nm. The resolution of the photodiode array is about 0.014 nm. The resolution of the photodiode array is about 0.014 nm.

Some examples of resolution are shown in Figure 47.

In general usage, the photodiode arrays show separation (but not to the base line) of two peaks of similar intensity if they are 4 diodes apart (.06 nm) and for two peaks with a considerable difference in intensity if they are 7 diodes apart (.1 nm). This may be enough to allow peak height correction unless one of the peaks undergoes considerable pressure broadening or is a strong enough emission to saturate the photodiodes.

The resolution of a pair of spectral lines is dependent on their individual line widths. This in turn depends on several factors including the source, the entrance slit, the diffraction grating and the spacing between pixels allotted for the detectors.

Within the spectral source the line width is controlled by several effects [12]. The natural line width at half intensity arising from the application of the Heisenberg uncertainty principle is generally of the order of  $10^{-5}$  nm, which is insignificant. Doppler broadening leads to half intensity line widths of the order of 0.001 to 0.01 nm. Collision or pressure broadening is much more important, particularly when strong Stark effects are present, as in the case of certain emission lines. The line width at half intensity is of the order of 0.1 nm for the H $\alpha$  line.





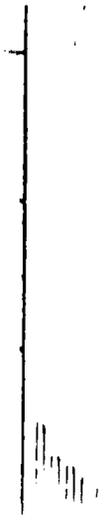


wavelength but have to be considered when such low wavelength ultraviolet lines are used in second order [11]

The diode ray output for a 15 ppm solution of sodium is shown in Figure 48(a). The  $D_{2}I$  line at 588.96 nm is stronger and broader than the  $D_{1}I$  line at 589.09 nm and causes considerable wing overlap. Because of this, the weaker  $D_{1}I$  line is generally used in direct measurements. The value of the  $D_{2}I$  line could be cancelled by subtracting the spectrum of water (to give Figure 48(b)) but this would require an error in analytical value and would contribute the same error due to variation in the concentration. The  $D_{1}I$  line allows an alternative method.

The  $D_{2}I$  line is real and symmetrical. Although the  $D_{1}I$  line is not, its position does not. It has been established that the  $D_{2}I$  value for the emission due to sodium is independent of the concentration of the sodium line and that the  $D_{1}I$  value for the emission due to sodium is independent of the concentration of the sodium line. The  $D_{2}I$  value for the emission due to sodium is independent of the concentration of the sodium line. The  $D_{1}I$  value for the emission due to sodium is independent of the concentration of the sodium line. The  $D_{2}I$  value for the emission due to sodium is independent of the concentration of the sodium line. The  $D_{1}I$  value for the emission due to sodium is independent of the concentration of the sodium line.

1.5 VOLTS



1.5

1.5



1.5 VOLTS



1.5



from its peak. The two subtraction methods are compared in Table 20 for five different samples with a sodium concentration range of from 4 to 20 ppm.

The effect of a high concentration of calcium on the aluminum line at 396.2 nm is shown in Figure 49. The curved baseline is due to the line falling on the extended wing of calcium II (396.8 nm). The aluminum line is also affected by line overlap from the line also due to calcium, next to it at 396.0 nm.

Sufficient of the curved baseline is present to allow the use of a curve fitting computer program developed by Moore [52]. This program is used to estimate the position of the baseline beneath the aluminum line. The program normally selects a fit to select a polynomial equation for the curve. It has to be used cautiously as it tends to attach too much significance to the irregularities in the curve. It may be possible to develop a more suitable program based on the expected profile of the background line. The program to be referred to the profile which is a combination of two or three peaks.

For the purpose of this study, the program was used to estimate the position of the baseline.

The program is based on level differences completely out for the purpose of this study. The program is used to estimate the position of the baseline.

The program is based on level differences completely out for the purpose of this study.

Table 20: Comparison of two subtraction methods for the removal of the argon interference on the sodium 589.0 nm line.

Peak Height in Volts Normalized To 1 Second Integration	
Water Spectrum Subtracted	Wing Value Subtracted
.01416	.01438
.01821	.01809
.01814	.01822
.01817	.01815

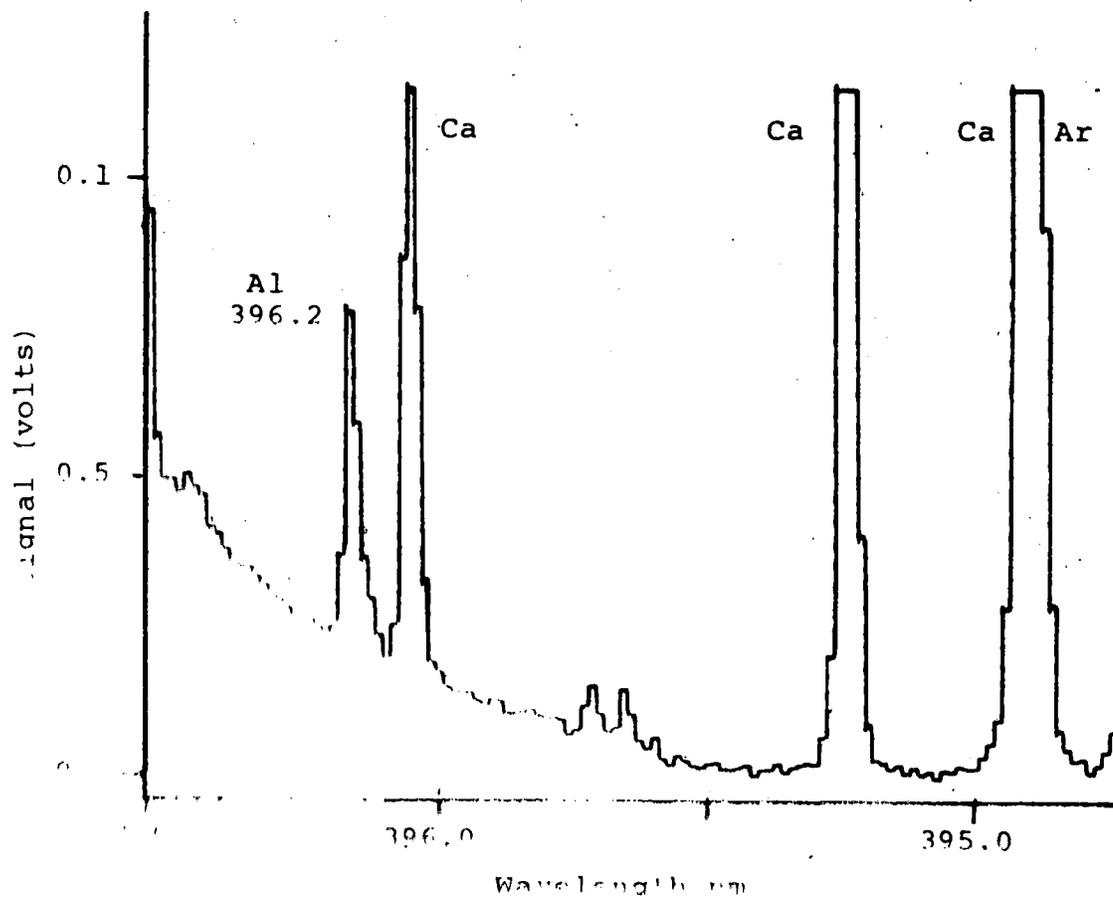


Figure 1. Interference by 100 ppm calcium on the aluminum  
396.2 nm line (3.1 ppm Al)

concentrations in the 2.5 to 10 ppm range. Some of this would be due to the wing overlap of the adjacent calcium line.

The collision broadened wings of the calcium line extend at least 2 nm from the line centre. Calcium, like the other alkaline earth elements, is highly ionized in the ICP and the ions undergo  $2S_{1/2} - 2P_{3/2,1/2}$  transitions to give spectral doublets corresponding to those given by the alkali metal neutral atoms. The emitting species is positively charged and exists in an atmosphere rich in free electrons. The ions are thus exposed to intense but variable electric fields. These fields cause perturbations in the energy levels of the single outer electron of the ion due to the application of the linear Stark effect. These energy level changes force variations in the spectral transitions and lead to the broadening.

#### 4. Direct Spectral Overlap

Direct overlap occurs when two spectral lines are close enough together so that their peaks cannot be resolved. This is a major problem with direct readers very near spectral lines of a concomitant element can cause significant spectral interference if the concentration of the element is high enough to cause a significant

The only solution is to calculate the signal due to the concomitant by measurement of its concentration with another spectral line. The apparent analyte concentration due to the concomitant is then subtracted from the measured analyte signal. Not all spectral overlaps are obvious and for those overlaps for which corrections are applied there is a deterioration of precision for the analyte due to the addition of the further uncertainty associated with each concomitant.

A direct overlap occurs when traces of zinc are determined in the presence of high concentrations of copper or nickel. The zinc line at 213.86 nm is overlapped by the minor copper line at 213.85 nm or the nickel line at 213.86 nm.

The direct reader was set up with three photodiode arrays covering the zinc 213.86 nm line second order at 427.71 nm, the copper line at 324.75 nm and the nickel line at 352.45 nm. There was a fortunate coincidence of a weak copper line at 427.71 which was recorded by the same array as the zinc line. The test solutions were 10 ppm zinc with 1500 ppm of copper or nickel. Solutions of copper and nickel (2000 ppm) were used as standards for calibration. The copper interference is illustrated in Figure 50. The minor spectral feature of copper causes significant interference when present in a much higher concentration than the zinc analyte.

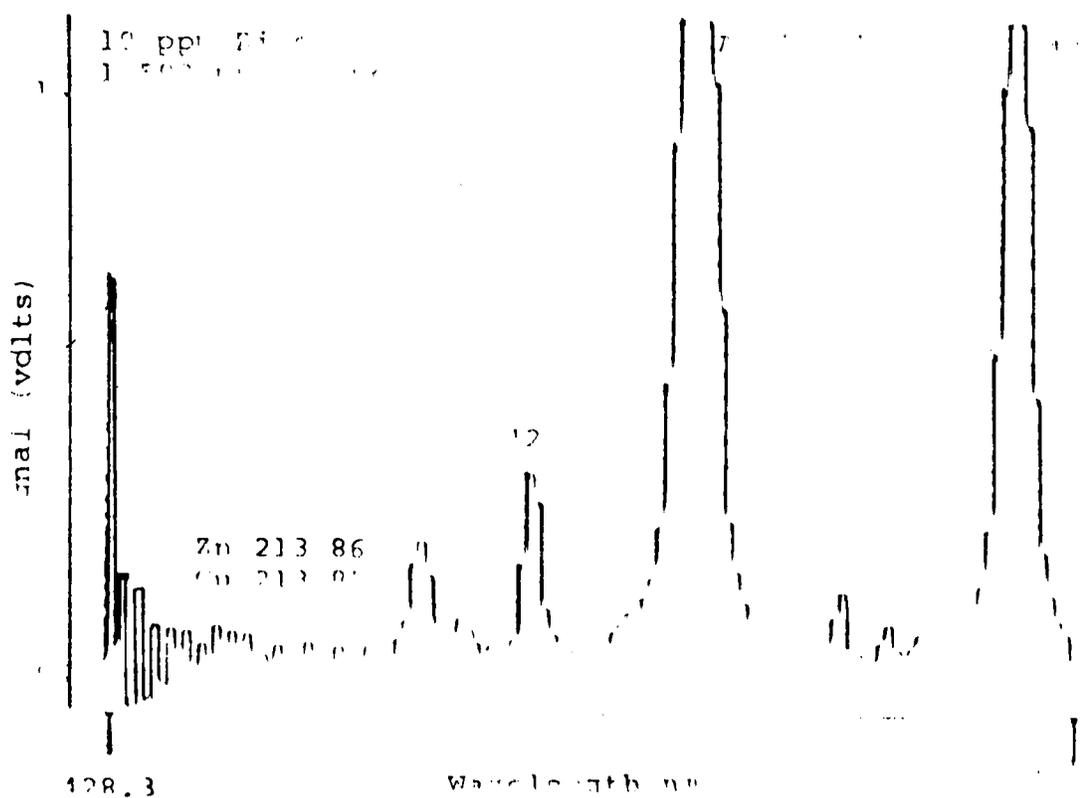
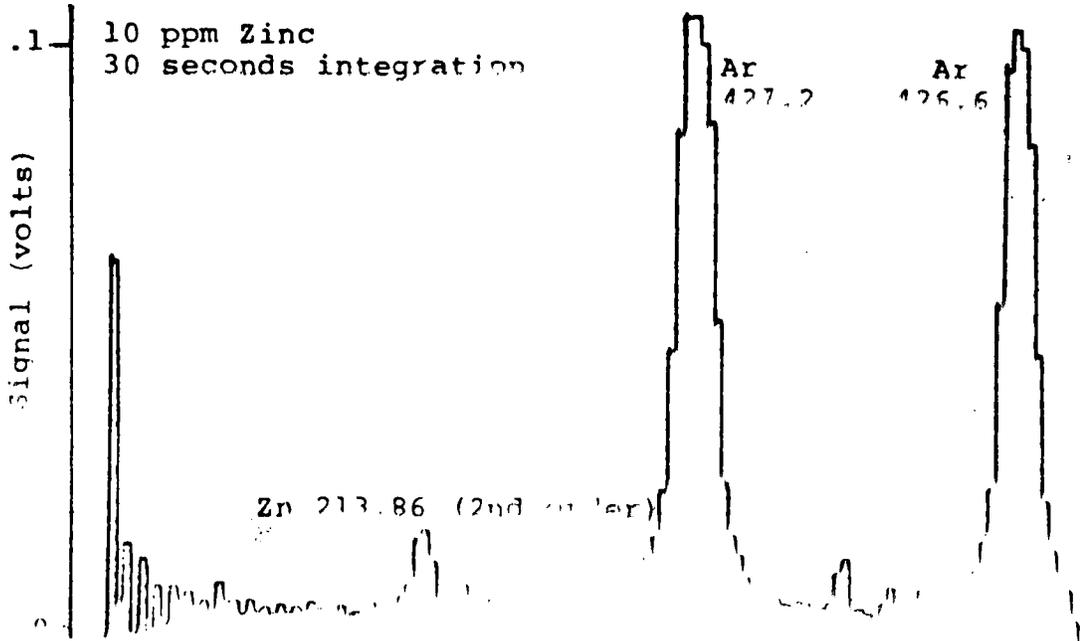


Figure 70

The corrective process is illustrated by Table 21. The correction calculated was a little low for the copper concomitant and too high for the nickel. The nickel correction error appears high until one considers that it involves a total measurement error of less than 4 mV. The standard deviation of the background against which the zinc signals are measured is of the order of 1.5 to 3 mV and the calculation involved the use of four sets of measurements (2 of the standard nickel line and 2 of the zinc line) and then comparison with a fifth.

The errors illustrate the difficulty associated with direct overlaps. Other workers have reached similar conclusions. Foster, Anderson and Parsons [51], following a basic study with a scanning echelle monochromator, state, "Direct spectral overlaps are not totally correctable and cause deterioration of detection limits and nonlinearity of analytical curves."

#### 4. Recombination Continua

The recombination of the singly charged ions of calcium, magnesium and aluminum with electrons in the plasma is known to raise the background level for spectral measurements at wavelengths below 302 nm. The effect on the background level was investigated by including 500 ppm of calcium, magnesium and aluminum (separately) into test

Table 11. Correction for direct overlap. See Figure 10.

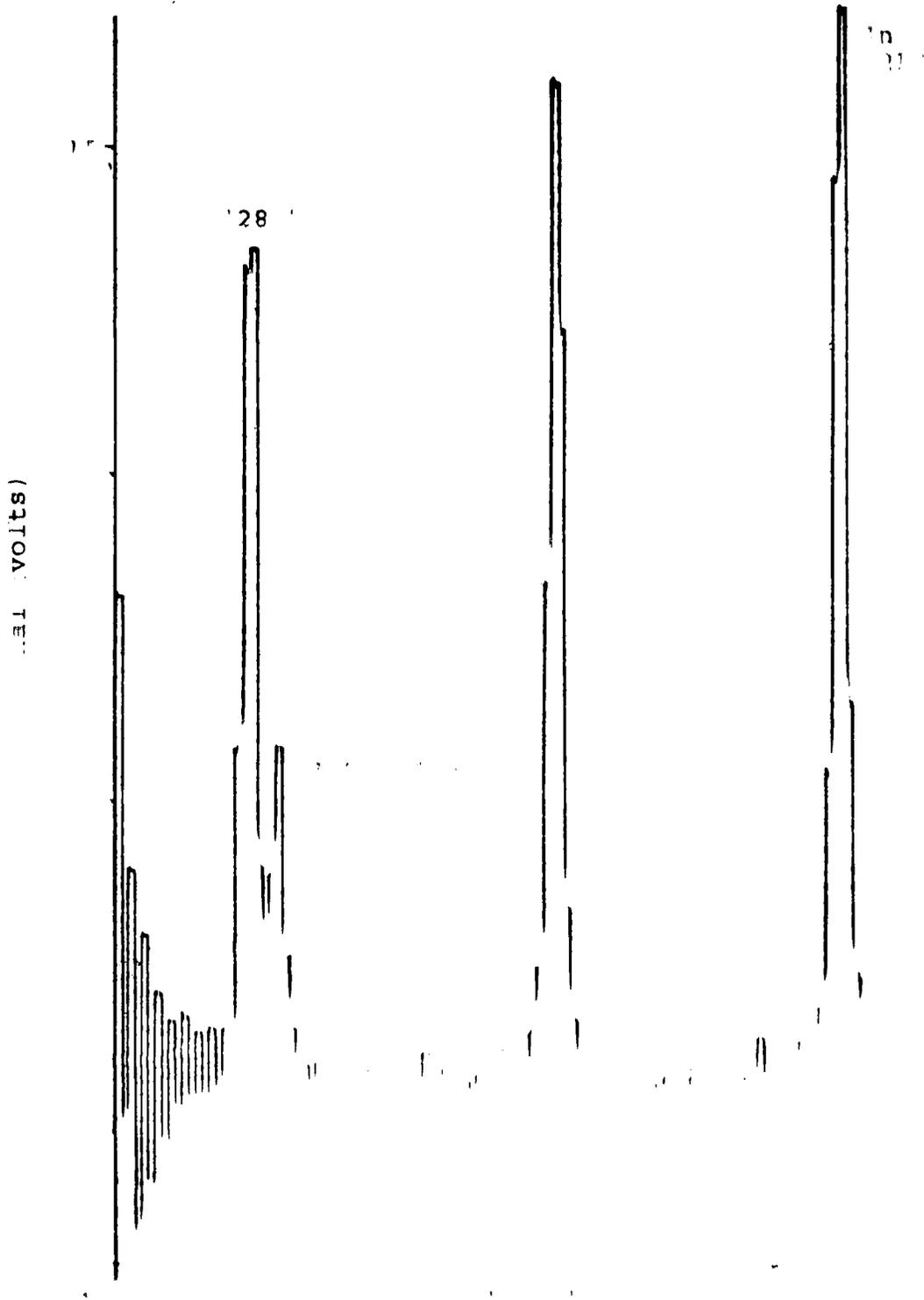
Signal Values in Volts Normalized to 1 Second Integration Time										
Test Solutions										
Wavelength (nm)	Standard Value of Signal	Standard Value of Signal	Signal Value for Cu	Signal Value for Ni	Signal Value for Zn	Signal Value for As	Estimated Zinc Signal	Estimated Zinc Signal	Signal for Comparison Taken on Same Settings)	Signal for Comparison Taken on Same Settings)
213.5 nm	0.2	0.2	0.20	0.20	0.35	0.35	4.46	4.46	0.06	0.06 x 10 <sup>-4</sup>
213.5 nm	0.2	0.2	0.20	0.20	0.35	0.35	4.65	4.65		
214.5 nm	0.59	0.59	0.526	0.526	0.20	0.20	6.80	6.80	3.07	3.07 x 10 <sup>-4</sup>

solutions containing 100 ppm of zinc and cadmium. The background was measured for the Cd I line at 214.4 nm and the Zn I line at 213.9 nm in both first and second order. No significant changes were noted in the diode to diode variation or in the background level.

Another wing overlap was noted between calcium I 428.936 nm in first order and cadmium 214.441 nm in second order at 428.882, illustrating again the advantage of having a spectral window (Figure 51). If the recombination continua had significantly raised the baseline, the use of off peak diode measurements to calculate the background would have automatically corrected for it.

##### 5. Stray Light Due to Grating Defects

There are three relatively strong emission lines in Figure 4, all due to calcium. They are at 396.0 nm, 395.2 nm and 394.9 nm. Not one of these lines appears in any published table of atomic emission lines. They are all Portland checks caused by periodic inaccuracies of the machine that ruled the master diffraction grating. They are relatively intense because their parent lines are extremely strong emissions. The line on the right appears broader than its neighbour because it has a stronger parent and also because it cannot be resolved from the

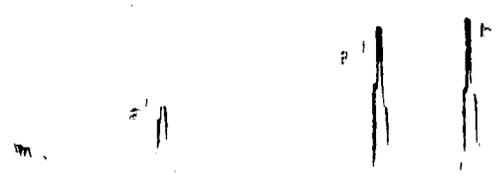
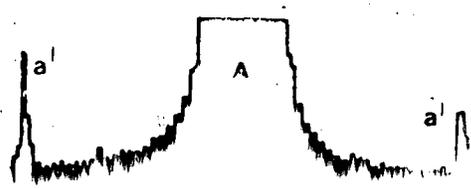


By use of separate measurements, the peak height of these ghosts was compared to that of the calcium II line at 396.8 nm. Reading from left to right in Figure 49, the peak heights of the calcium ghosts compared to the 396.8 nm parent are .0032, .0075 and .0077. The first line is the first order ghost from the 396.8 nm parent, the second line is the second order ghost from the same parent and the third line is the first order ghost from the parent calcium line at 448.1 nm.

The diode array window is not wide enough to show the whole symmetrical pattern of the ghosts. By moving the array along the focal plane of the direct reader, the whole pattern can be found. This is illustrated in Figure 50 which also shows how the broad wings of the parent lines can dominate the background for any other elemental lines in this region of the spectrum.

More modern gratings ruled with interferometric techniques are claimed to have first order ghost to parent line ratios of 0.001 [10]. That is, the ghost is only one thousandth as bright as the parent line.

The ghost intensities illustrated by Figures 49 and 50 are very low in comparison to those seen with a grating ruled conventionally. However, it must be considered that the diode array reader is obtained as a working instrument from a commercial installation with the grating ruled by



a 100.0

b 100.0

c 100.0

d 100.0

e 100.0

f 100.0

The grating defects characterize the ruling engine  
to make the master grating.

The grating defects is given by (31)

$$\lambda' = \lambda \left( 1 + \frac{m'}{m} \right)$$

where  $\lambda$  is the wavelength of the parent line,  $\lambda'$  is the  
wavelength of the ghost of order  $m'$ ,  $m$  is the spectral  
order of the parent line and  $p$  is the number of lines  
per revolution of the lead screw of the ruling engine.

For example, an engine ruling 700 lines for each full turn  
of the lead screw would expect to have ghosts at intervals

of  $\frac{1}{700}$  of the central region of the grating and this

is the same for all orders.

For a grating with a central region of  $10^6$  lines, the

$$m^2$$

ghosts are displaced by  $\frac{1}{700}$  of the displacement

of the parent line. The displacement of the parent line

is given by

If the displacement is taken to first order, the

displacement can be calculated as 1.88, which for an

engine ruling 100 lines per revolution would give an

error of 0.00188 in the displacement.

Returning to the problem of interference with the aluminum line, there is an alternative aluminum line at 394.4 nm. This is only 60% as intense as the line at 396.2 nm but for this grating and for a matrix high in calcium, it is the better choice because it lies further from the first order ghost, in this case, of the calcium 393.4 nm line. Thus the spectral window provided by the phoswich is very small. The same data is shown in Figure 10. The lines to which the phoswich is sensitive are indicated by the arrows.

#### Interference from Molecular Bands

All of the spectra considered so far have been due to electronic transitions within an atom. However, certain molecular species can also exist in the plasma and these undergo vibrational and rotational transitions as well as electronic ones. Just as the rotational transitions add fine structure to vibrational spectra in the infrared region, so the vibrational and rotational transitions add fine structure to the electronic spectra in the ultraviolet region. The intensity of the fine structure is dependent on the temperature of the plasma. At low temperatures the fine structure is well resolved, but at high temperatures the fine structure is completely unresolved. The fine structure of the calcium 393.4 nm line is shown in Figure 11. The arrows indicate the positions of the fine structure lines.

The calcium 393.4 nm line is particularly sensitive to the temperature of the plasma. The fine structure is well resolved at 1000 K, but is completely unresolved at 10,000 K.

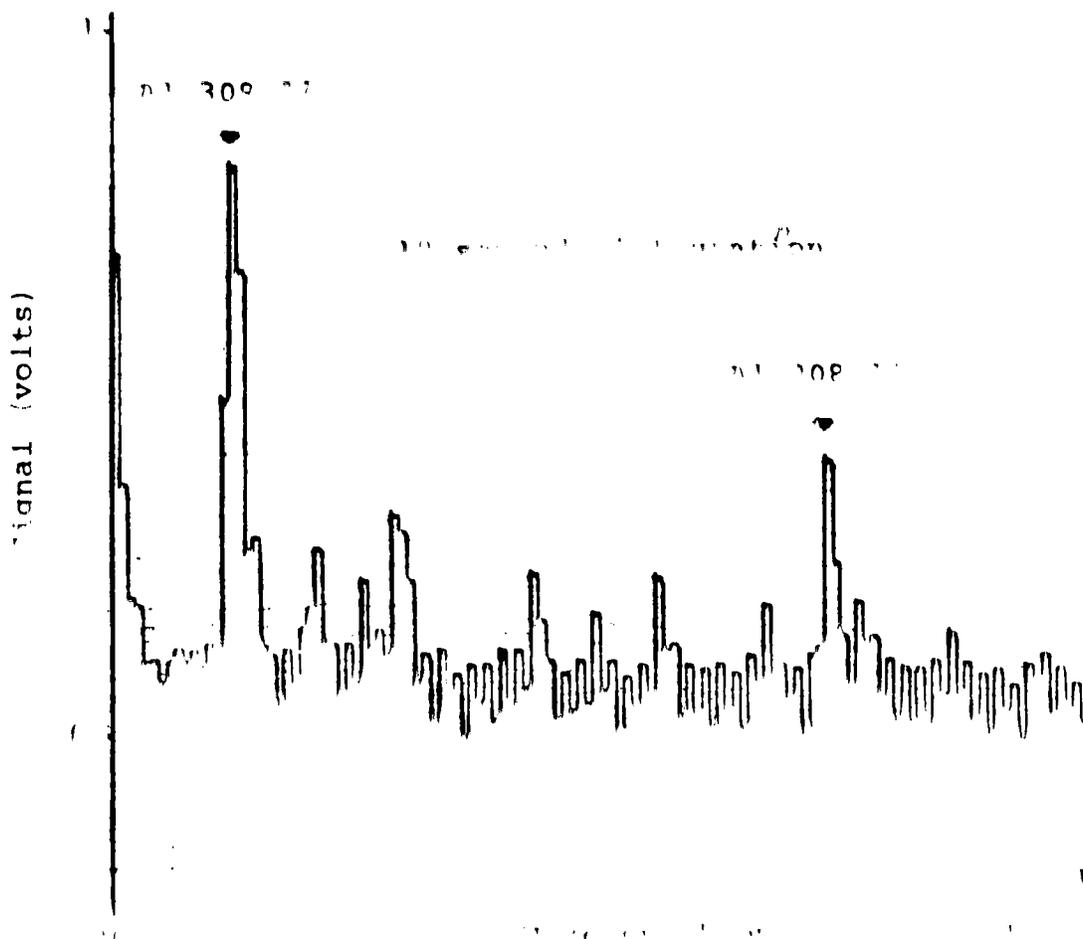
organic compounds are avoided. If the flow rate of the plasma (coolant) gas is high enough, the NO and NH spectra are not a problem. However the OH bands are always present when aqueous solutions of analyte are used.

### 6.1 Problems Caused by Hydroxyl Bands

Dieke and Crosswhite [54], working with an oxy-acetylene flame source and a 21 ft radius diffraction grating, identified hydroxyl lines over the range 281.1 nm to 351.6 nm. Many of these lines are of low intensity and do not cause interference but some are intense enough to cause serious problems. According to Foster, Anderson and Parsons [51], the ICP background contains 116 major hydroxyl features between 281.0 nm and 294.5 nm and a further 170 between 306.0 nm and 324.5 nm.

As a typical example of the interference caused by hydroxyl consider Figure 5<sup>o</sup> which shows the aluminum lines at 309.3 nm and 308.2 nm for a 10 ppm solution and 10 second integration time. The aluminum I 309.3 doublet (unresolved) and the aluminum I 308.2 line are obscured by the background plus other spectral features as well as the order zero pattern of the array. It is not clear which value of background could be used to correct the aluminum lines.

It is clear that the use of the background of the array



01 300 07 01 008 07

due to aspirated water obtained. This is shown with the signal axis extended in Figure 54. All of the peaks are due to hydroxyl and can be assigned to transitions using the tables published by Dieke [54]. The aluminum I doublet at 309.271 and 309.284 nm is augmented by the hydroxyl peak at 309.279 nm with another more intense hydroxyl peak close by at 309.239 nm. The aluminum I line at 309.215 nm lies in a trough between the major hydroxyl peaks but has a minor peak at 308.207 nm on the next diode which, combined with the effects of major peaks at 309.167, 308.162 and 308.154, raises its background level.

Corrections would be required for both the 309.3 and 308.2 nm aluminum lines. There are two possible ways to correct for the hydroxyl interference. One is by direct subtraction of the water signal and depends for its precision on the water signal being constant. The other method is by estimating the contribution of the hydroxyl emission from another hydroxyl peak on the same array but away from the aluminum lines. Neither method is really satisfactory. The water subtraction is shown in Figure 55. The peak height for aluminum at 309.3 nm after subtraction of water background was .03273 V with a background standard deviation of .00232 V (4 points). However, the standard deviation of the water background is .00232 V (4 points) and the standard deviation of the aluminum signal is .00232 V. Thus the variability

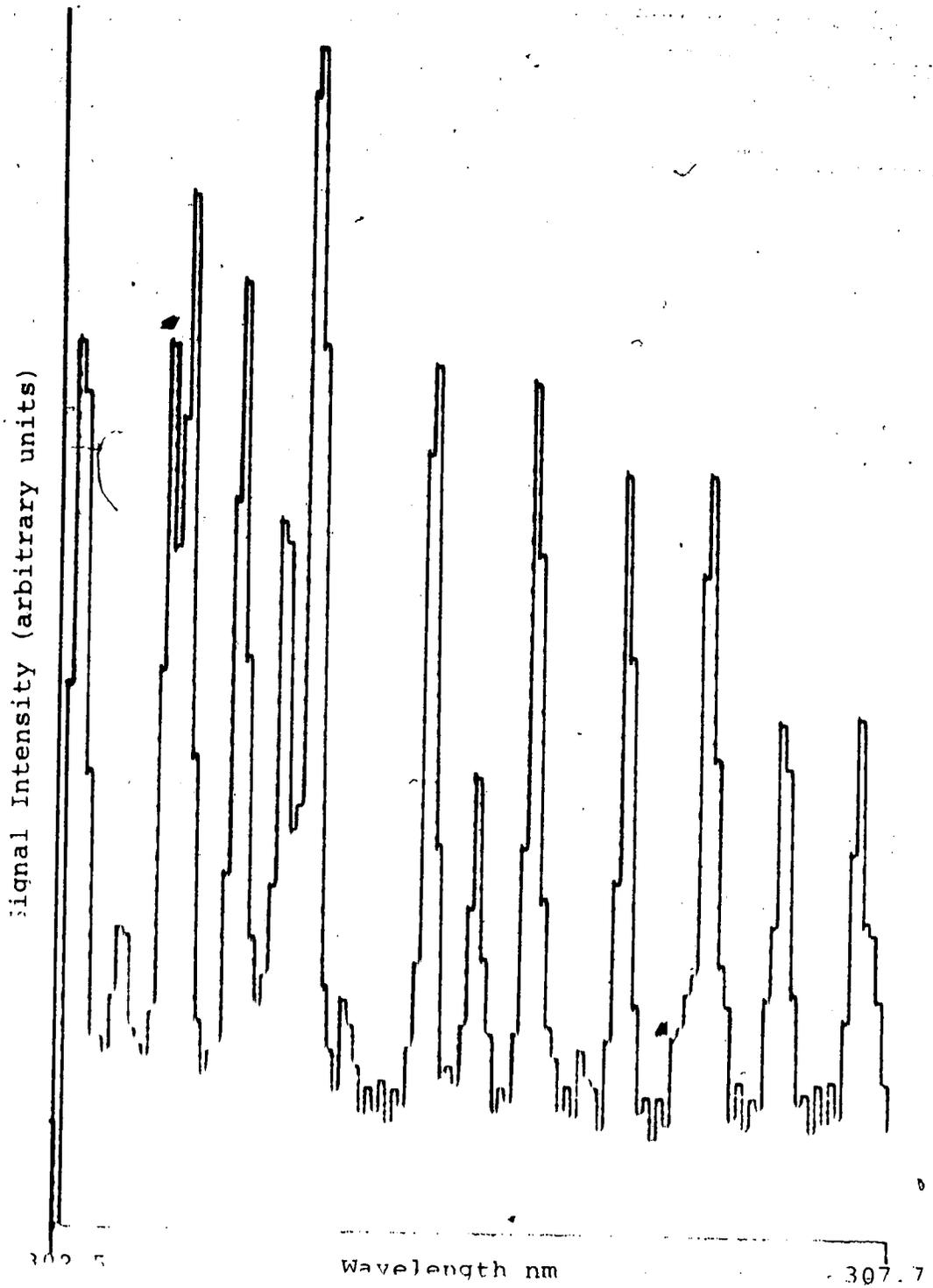


Figure 54. The hydroxyl pattern for water in the 308 nm to 309 nm range. (The arrows indicate where the aluminum lines would be.)

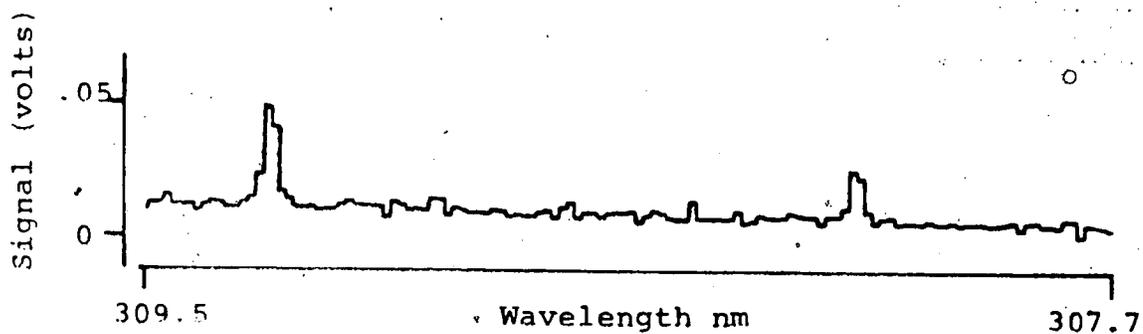


Figure 55. The aluminum lines, at 309.3 nm and 308.2 nm after water background subtraction. 10 seconds integration. 10 ppm Al.

of the signal due to the hydroxyl background reduced the signal to noise ratio of the analyte line from 17 to 5.5.

Aluminum has its three most sensitive lines subject to spectral interferences. This has led to the use of the doublet at 237.3 nm for aluminum in photomultiplier tube based direct readers. In order to ease the crowding of the focal plane array of a direct reader in the ultraviolet region, this emission may be viewed second order where it is within .05 nm of a weak argon line at 474.7 nm [51]. This type of close proximity of spectral lines to potential interferences forces the instrument manufacturer to use narrow exit slits and to go to considerable trouble to maintain constant optical positions for the exit slits. This may involve thermostatic control of the whole direct reader dark box and the maintenance of a constant atmosphere within it.

The hydroxyl spectra are much weaker in the region of the copper I line at 327.4 nm. Integration times of ten times those used for the aluminum area were required before they became significant (100 seconds versus 10 seconds). They are illustrated in Figure 56. Again Dieke's tables [54] allow the peaks to be assigned to transitions.

The 327.396 nm copper line is close to a hydroxyl line at 327.421 nm. The alternative copper line in the

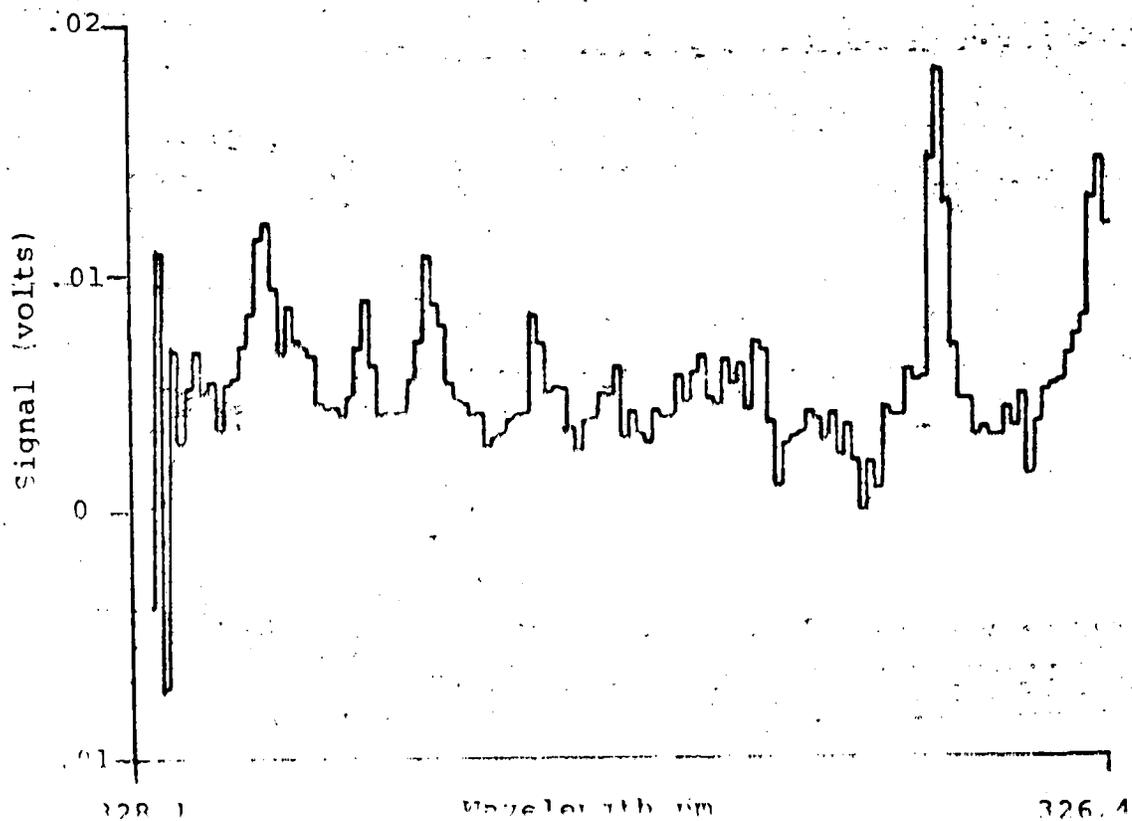


Figure 56 The hydroxyl pattern in the 327 nm to 328 nm region for 100 seconds integrations.

same region at 324.754 nm is close to the hydroxyl lines at 324.736 nm and 324.762 nm. However the intensities of the hydroxyl lines, as measured by Dieke, are about one fiftieth of those in the aluminum region and this reduces their effect on the detection limits of the analytes.

### 6.2 Problems Caused by Nitric Oxide Bands

The cadmium II line at 214.4 nm is in the same spectral region as a NO band head if the molecular bands are present. The spectrum recorded for 50 s integration time of a 1 ppm cadmium solution is shown in Figure 5. The cadmium 214.4 nm line is shown in second order at 428.9 nm. The black arrows indicate single diode anomalies that become significant at long integration times. The features marked b and the general increase in background towards the longer wavelengths are present in the spectrum of water and may be due to molecular species or to stray light.

Because the spectrum is second order, direct assignments are difficult to make. The band head of NO bands, that has been observed for the ICF at low plasma gas flow rates, has a band head at 214.91 nm (429.82 nm in second order) [55], just to the left of the array. Application of a pair averaging technique to reduce the effect of the diode pattern to the left of the array will reduce the stray light due to the background band.

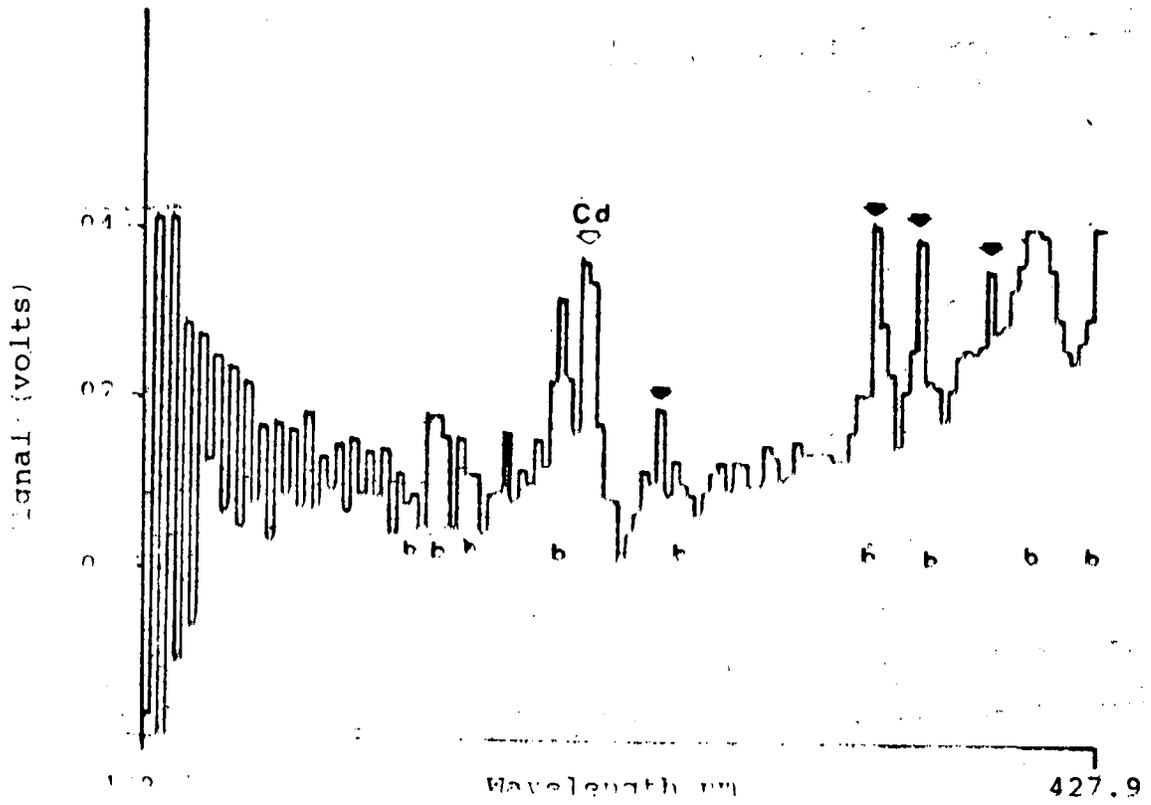


Figure 57 Background patterns near the Cadmium II 214.4nm line (second order) - 50 seconds integration.

longer wavelengths, not as large an effect as that to the right, lower wavelength end, of the array. Although no direct assignments could be made, there are enough background features to complicate the reading of a cadmium signal.

### Use of the Direct Reader for Analysis

One of the advantages that the photodiode array has over the exit slit photomultiplier tube combination is the ease of location of spectral lines. This allows the diode arrays to be moved along the focal plane of the direct reader to suit the analytical problem. Because the detectors are easily moved, the number of detectors can be reduced. Banks of 40 to 60 exit slits each with its own detector are no longer necessary. The diode arrays can be placed to detect the elements of interest in a particular analyte sample. The direct reader is compact and overlapping elements can be detected in a small area. The array can be used to measure small amounts of analyte that spectral lines are present in the range of the array. The array can be used to measure small amounts of analyte that spectral lines are present in the range of the array. The array can be used to measure small amounts of analyte that spectral lines are present in the range of the array.

To demonstrate the flexibility of the photodiode array direct reader it was set up to measure the main metallic elements in several commercial bottled waters. Three bottled waters from three different sources were obtained. To add variety a locally produced beer, a local well water and the municipal supply were also analysed.

The elements determined were calcium, iron, magnesium, manganese, sodium and strontium. Potassium is also usually present in water samples but the potassium 766 nm emission is too weak an emission for analysis of ppm level concentrations. The much stronger emission at 766 nm is just outside the normal geometric range of the direct reader (it could be brought into range if a shorter array or a lens could be made). Zinc is also of interest but it could not be obtained simultaneously with the other elements because of the little window of the direct reader with the width of the array covering

To determine the limits of the direct reader the direct reader was set up to read using the direct reader. The direct reader was loaded on the direct reader. The direct reader (including the direct reader) was set up to read a list of 141 elements. This direct reader had a list of 141 elements. The direct reader was set up to read the direct reader.

Most of these features were ruled out as analytical lines by considering the instrumental limitations of the direct reader combined with some knowledge of the concentration ranges to be expected. The remainder were carefully examined and the following are presented with their corresponding wave numbers.

Ray 0

- Mn I 260.6 nm
- Fe II 259.9 nm
- Fe II 259.8 nm
- Fe I 260.0 nm

Ray 1

- Mg II 293.7 nm
- Mn II 293.3 nm
- Mn I 293.0 nm

Ray 2

- Ca I 422.7 nm
- Ca I 422.7 nm

Ray 3

- Na I 589.0 nm
- Na I 589.0 nm

Below are listed the wave numbers of the lines which were not included in the above list. These lines were either too weak to be detected or were not included because they were not in the range of the instrument. The lines are listed in order of increasing wave number.

4000-4500 cm<sup>-1</sup>

4500-5000 cm<sup>-1</sup>

5000-5500 cm<sup>-1</sup>

5500-6000 cm<sup>-1</sup>

6000-6500 cm<sup>-1</sup>

6500-7000 cm<sup>-1</sup>

7000-7500 cm<sup>-1</sup>

7500-8000 cm<sup>-1</sup>

8000-8500 cm<sup>-1</sup>

8500-9000 cm<sup>-1</sup>

9000-9500 cm<sup>-1</sup>

9500-10000 cm<sup>-1</sup>

Solution standards were prepared at high and low concentrations for the elements of interest. The concentrations were selected to straddle the expected ranges of the elements in the samples. The samples were analyzed with the integration times for the various arrays selected to bring the signal values within the dynamic range of the arrays. Data values were extracted from the array signals and concentrations calculated by linear interpolation of the values for the solution standard.

The iron II line at 250.9 nm was subject to background patterns and gave signals with considerable variability so it was not selected as an analyte line.

The results are given in Table 22 and compared to values reported on the bottle labels and to a previous sampling of the local waters analyzed last year with a 1000 multiplier tube based direct reader.

The precision (relative standard deviation) of the measurements of the calibration standards were in the 1-2% range for all elements measured, and the higher the integration time. The precision of the analyte runs for the iron element varied from about 1% to 12% depending on the concentration. The precision for the other elements was generally better than for iron. The precision for the iron element had a relative standard deviation of 10%.

For comparison the relative standard deviation was 10% while for the iron element it was 12%.

2. Analytical results for water samples.

VALUES IN PARTS PER MILLION									
SAMPLE	Ca	Mg	Na	K	Fe	Mn	Cl	SO <sub>4</sub>	CO <sub>3</sub>
TOTALITY	11.7	93.7	21.6	139.6	189.0	260.6	260.7	259.8	
Carrier Water	12	59	3	4.0	*	*	*	*	*
Collinarius Water	11	10	14	53	58	*	*	*	*
De Blanc Water	16	1	16	3	*	*	*	*	*
Water Red Deer	5	10	27	13	1.22	1.8	2.1		
Well Water	2	0.9	2	5	1.44	4.7	4.6		
Municipal Water	3	33			*	*	*	*	*
TICAL VALUES FROM BOTTLE LABELS									
Carrier Water	40	5	1	4	4	4	4	4	4
Collinarius Water	45	5	17	172	172	3.03	0.02	0.02	0.02
VALUES FROM PREVIOUS SAMPLINGS 561									
Well Water	1	1	1.65	5	5	1.37	3.7	3.7	3.7
Municipal Water	10	10	46	10	10	10	10	10	10

Flow detection limits of 0.02 ppm for Mn and 0.2 ppm for Fe.

concentrations of manganese and iron necessitated the use of long integration times with consequent build up of background irregularities.

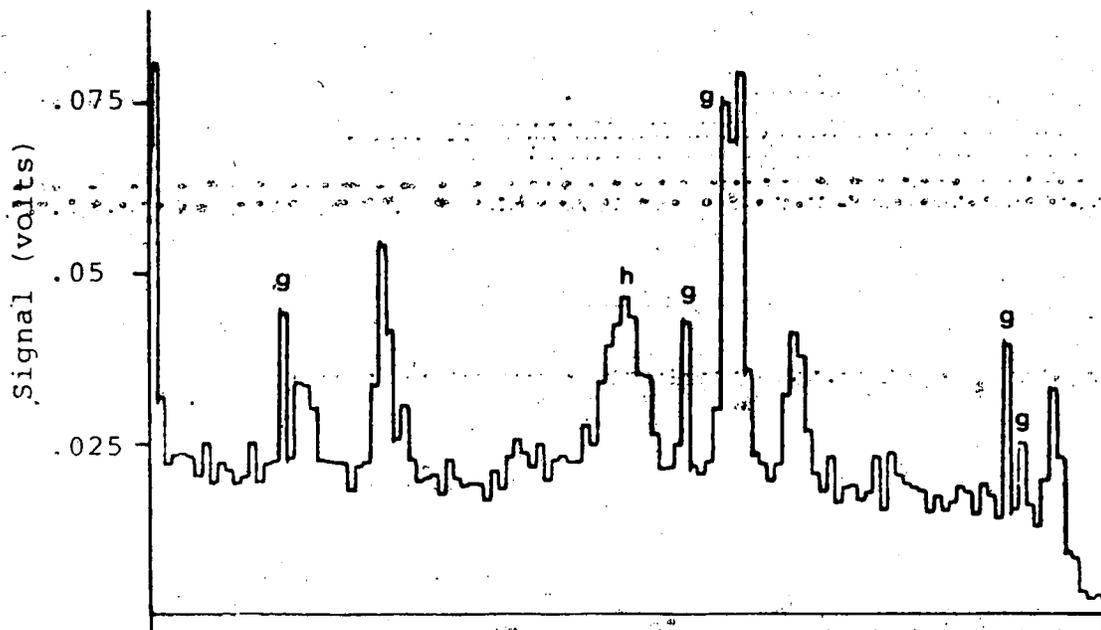
#### 8. Background Subtraction and Other Correction Methods

The photodiode array output displayed on the video monitor allows direct inspection of the background against which the emission signal must be measured. With the exception of direct overlaps, all interfering spectral features become obvious. Because both the analyte line and the background are recorded by the data logging system and if required saved to disk, the correction method can be selected and applied later.

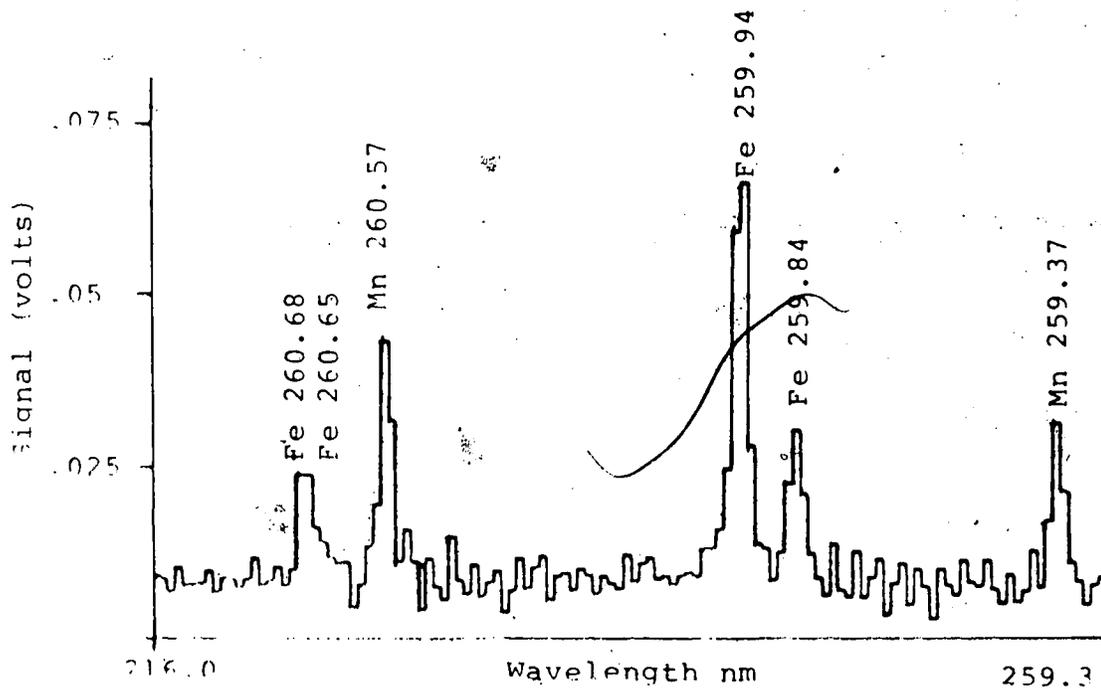
Background corrections can involve the complete subtraction of a measured background spectrum or the calculation of a baseline value from off-peak diodes of the same analytical run or both. If the background level is reproducible between data measurements, a simple background subtraction is sufficient. However, especially with measurements involving long integration times for low analyte concentrations, it is usually followed by use of an off-peak background correction factor.

Background subtraction is useful for removing or reducing the interference generated in the source other than the elements of the analyte matrix. If they are





(a) Spectrum of well water



(b) Spectrum of well water with water background subtracted.

Figure 58 The manganese and iron spectrum of well water, showing subtraction of array artifacts.

If concomitants in the analyte sample cause interference, then background subtraction will not suffice although it may be used to reduce odd-even pattern as a preliminary step. For concomitant interference, corrections must be obtained from the same analytical run. If direct overlap occurs the correction involves measurement of the concomitant elsewhere on the same or another array and prior calibration of the overlapping signal. For wing overlap, the same process can be used but may not be necessary. It may be possible to predict the corrected baseline value beneath the analyte line by estimating the contribution to the total diode signal from the interfering concomitant.

All calculations or projections involving an interfering signal increase the detection limits by reducing the precision. The diode array allows the operator to obtain prior knowledge of the symmetry of the interference imposed by the concomitant and this can be used to correct from the analyte run data. A complete printout of the diode values during the evaluation of the interference assists in this process.

The extraction of the analyte peak height has been incorporated as a system program. One of the options available in this program allows the operator to identify the diode to be used in calculating the background level

in much the same manner that the interpreter of a spectrograph photograph can select the positions for measuring the background intensity with a densitometer.

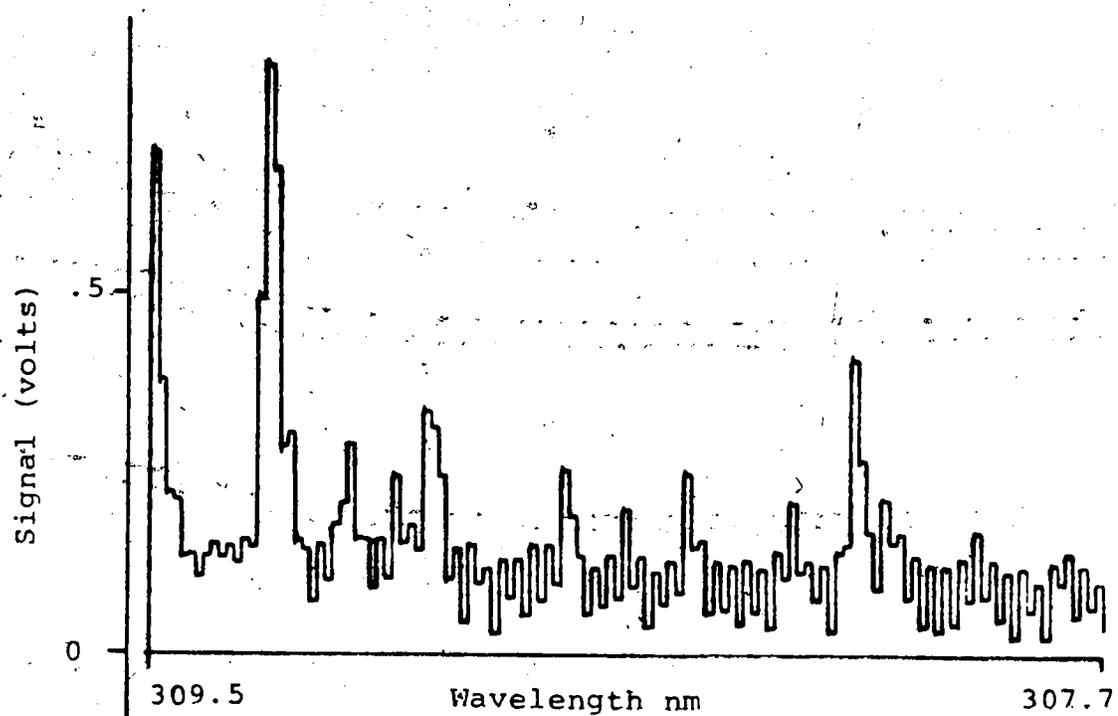
The odd-even pattern of the array must be considered when calculating the background to be subtracted. One of the options in the peak height extraction program automatically considers the odd and even diodes as two separate populations.

An alternative method to remove the odd-even structure from the spectrum is the use of pair average smoothing. The effect of this is shown in Figure 59. If this technique is used it must be used consistently for both analyte and calibration runs. It does reduce the resolution of the spectrum.

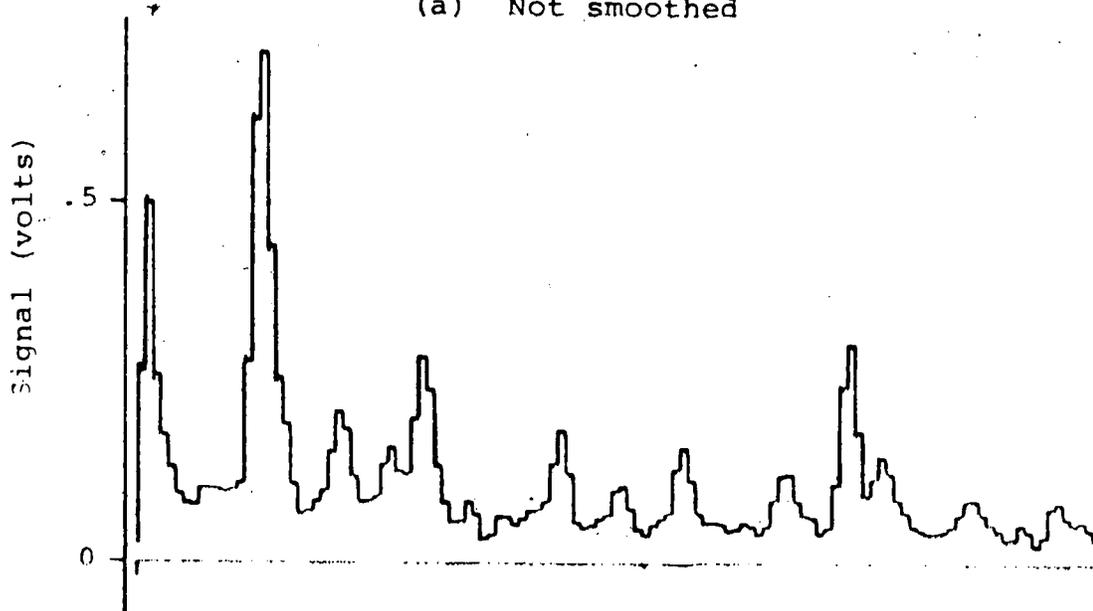
Continuous concomitant interferences such as recombination continua and scattered stray light are compensated for by the peak extraction program.

This concludes the description of the design, construction and use of a photodiode array direct reader. Its spectral windows have been used to remove many of the limitations of the photomultiplier tube based instruments.

In particular it compensates for spectral interferences and imparts versatility. In doing so it restores to spectroscopic analysis the more favourable



(a) Not smoothed



(b) Pair averaged

Figure 59. The smoothing effect of pair averaging on the odd-even pattern.

characteristics of the photographic method that were sacrificed in the cause of electronic readout.

This instrument is still only a step along the way to an optimized electronic imaging direct reader. The basic principles have been explored and put into practice within the limits of the equipment made available. The present design is not perfect and there are several problems to solve before the perfect instrument can be built. Some of these have been discovered during the development of this system and are described in Chapter VII.

## CHAPTER VII

### UNSOLVED PROBLEMS AND DIFFICULTIES

The photodiode array direct reader constructed was a modular system. As a prototype it was assembled from components, most of which were designed for other purposes. Consequently a lot of compromises were necessary.

This chapter describes some of the difficulties encountered and not fully solved. The instrument has great potential but further work is necessary to improve the mechanical, electronic and optical characteristics. Some of the problems are a function of this one particular instrument and now that they are recognized could be designed out of any future instrument.

#### 1. Alignment Problems

Due to its physical size, shape and weight, the light proof box of the direct reader could not be mounted on any of the standard optical rail beds that are used in the laboratory. It was mounted on a fixed stand. All alignment of the instrument had to be made on this stand.

and adjusting the optical rail bed carrying the spectral source and any external optics. Because the whole system was not on a single mounting, the alignment was easily lost. Complete redesign of a new instrument on a single mounting would eliminate this problem.

## 2 Illumination of the Grating

The diode array does not have the high signal gain of the photomultiplier tube and needs to receive as much of the signal generated by the source as possible. The  $f$ -number of the grating with respect to the entrance slit was 19.4 (grating width 6.3 cm and distance from the entrance slit 122 cm). The external optics controlling the illumination of the entrance slit should have a similar  $f$ -number. It was found experimentally that short focal length lenses (10-12 cm) gave no better illumination of the grating than those of longer focal length (25-30 cm). Although shorter focal length lenses could gather more of the emission from the source, they overfilled the grating and merely added to the stray light entering the system. The multi array system was set up with a 30 cm focal length, 5 cm diameter, quartz lens, optimized with the lens 68 cm from the entrance slit and 50 cm from the plasma plume. Thus the image of the plasma plume was focused to form the entrance slit. The entrance slit

was illuminated by light originating 10 to 23 mm above the load coil of the plasma source. A 5 cm diameter lens 50 cm from the source gives a small solid angle, gathering only 1 part in 1,600 of the light emitted by the source.

In a redesigned system with a single mounting, a collimating light collection lens could be used to get the more of the emission. A collimating lens 10 cm from the plasma plume would collect 25 times the light level collected by a lens at 50 cm. A more detailed analysis of a grating with a smaller radius would indicate the reciprocal dispersion at the focal length of the lens. The number for the order of the grating is

### 3. Grating Defects

The light losses in the UV region due to inappropriate blazing of the grating were considered. Second order intensity for the line 213.9 nm and the 214.4 nm lines were six times the first order intensity. Additional evidence of the rapid deterioration of grating output at short wavelengths has been observed in simultaneous measurements of the first and second order intensities as a function of wavelength.

The present work was supported by the Office of Naval Research, Washington, D. C. The author is indebted to R. J. ... for his assistance.

0.12 to 1. The disparity between the two instruments involves a factor of 29 for measurements of two lines only 123 nm apart. This would suggest that the intensity loss for the zinc and cadmium lines is only partially regained by changing to second order.

A diffraction grating specifically blazed for the lower wavelength required for the ICP should lower the detection limit in the ultraviolet region down to the photomultiplier tube detection limits. However, this requires experimental verification.

The ghost ratio can be reduced by using a better quality grating.

One manufacturer [10] claims that a ruled grating should have a percent to ghost intensity ratio of  $10^6$  to  $10^4$ , much better than the 123 of the grating used. Ghosts can be eliminated if a holographic grating is used. However, the efficiency of such a grating is a function of wavelength relative to the grating line intervals. They cannot be easily blazed for efficiency like a ruled grating can. It is claimed [10] that a holographic grating is most efficient at wavelengths up to 0.8 times the grating interval. Thus a holographic grating with 0.8 times the groove interval would be most efficient at the wavelength of the zinc and cadmium lines.

#### 4. Stray Light Introduced by the Circuitry

The photodiode array direct reader has a considerable amount of circuitry mounted inside the dark box. This is necessary as the RC1024S drive boards have to be close to the diode arrays. Although the mounting boards are blackened, there is a considerable amount of circuitry with reflective surfaces (see Photograph 3). The diode arrays are in the focal plane of the direct reader and light reflected back, from the metal surrounding the diodes, towards the grating will be re-focused elsewhere on the focal plane. If the wavelength of the reflected light is long enough secondary diffraction can occur and interference at lower wavelengths. Greater interference could be expected from the reflected light if there is an unruled portion of the grating blank.

A finely divided grating of fine ruled period of the array will direct the light to a focal plane where it will be detected. The light will be detected at the focal plane of the system.

Light that is scattered by the circuitry will be focused at the focal plane of the direct reader. The light will be detected at the focal plane of the system. The light will be detected at the focal plane of the system.

COLOURED PAPER  
PAPIER DE COULEUR



COLOURED PAPER WITH AIR DIODE

No major stray light problems have been observed but they are possible. Reflections off the array surrounds would be hard to reduce although their effect might be reduced by masking the unrulled portion of the grating blank. If the reflection occurs behind the array it can be reduced by covering the offending circuitry with black velvet.

#### 5. Limitations on Spectral Window Selection

The width of the sensing part of the 128 diode array is 3.2 mm. The array chip itself is 27 mm wide and the mounting carriage width is 43 mm. Consequently there are strict limitations on the selection of spectral windows; only about 7% of the spectral width occupied by the carriage can be sampled. Once a window has been selected the next window has to be at least 1.5 mm away from it.

Diode array arrays available in the marketplace, with 512 and 1024 diodes. The 1024 diode array has a sensing width of 25.6 mm and will fit in the same carriage. The diode array is ruled with a 100 micrometer pitch. The ruling is on the carriage. The chip is ruled and offset. The surface of the mounting plane will cause the light to reflect the light into an array mounted in a different plane. The software is easily modified to account for the geometry of the diode array.

Because the diode arrays are planar and the Rowland circle is curved, parts of the array are always out of focus. With the 1024 diode array this amounts to 0.1 mm focussing error for a 150 cm diameter Rowland circle and 0.2 mm error if a 75 cm diameter Rowland circle were to be used.

#### 6. Possible Blooming Problems

If two lines of very different intensities fall close together on the same array, there may be some blooming problems. Talmi and Simpson [23] describe blooming effects in diode arrays as sequential overspill from diode to diode so if a weak line is too close to a very intense line, the diode saturation of the latter could wipe out the weaker line. Busch and Benton [57] describe this as a drawback of the diode array detector. This, however, reduces the versatility of the array system. If one line is saturated by a much stronger neighbour, another analytical line must be selected.

There are very few elements that do not offer a selection of analytical lines with the inductively coupled plasma. If there is no alternative the edge of the array may be used or part of the array may have to be used to detect a line out of the array.

## 7. The Dark Current Problem

When the decision was made to use the smaller Peltier coolers for the six array system, it was considered that this would cool the back of the arrays to  $-21^{\circ}\text{C}$  and that this would be cool enough. However, several of the arrays are obviously inadequately cooled. This shows up for integration times of 10 seconds or more as single diode glitches (Figures 57 and 58) and in one case as a major dark current artifact. These abnormalities are generated on the array, by the array, as they are diode specific and are probably due to manufacturing defects. As larger Peltier coolers would require a considerable increase in the DC power required to drive them, further cooling could be achieved by replacing the cooling water with a chilled fluid cooled in a closed system by refrigeration. In order to maintain flexibility, it may be necessary to change the type of coolant distribution hoses used. If the cooling fluid is too cold, the hoses may become brittle with condensation or ice.

There may be another factor contributing to the cooling problem. The diode arrays are held in place by their 22 pins in their sockets. The arrays are cooled by the cold leg of their coolers through a thermally conducting paste. Heat transfer from the array is

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possible and this requires pressure. The only pressure acting on the arrays, to push them onto the cold bar, is exerted by the black plastic mask fitted to contain the dry nitrogen flow. This pressure is transmitted to the array through small pieces of sponge rubber which may or may not retain their elasticity at low temperatures. When the array is cooled and later allowed to warm up to room temperature, there will be an expansion-contraction problem caused by the use of different materials for the cooling bar, socket and mask. This may cause the array to work away from the cold bar. A review of the design of this heat transfer system should be considered as a first step in the reduction of the dark current problem.

Because the peak evaluation techniques utilize measurements of values for off-peak diodes, it is important that the dark current be limited not only to allow sufficient signal dynamic range, but also to reduce the diode to diode dark current variation. This latter adds to the uncertainty of the background values.

According to Vogt [25], when the dark current exceeds about 5% of the diode saturation readout value, the shot noise in the thermal leakage becomes the dominant source of noise. This does not appear to be the case for the direct reader as its background variability is much greater than that which could be generated by dark current shot noise.

The dark current shot noise  $N_d$  (in electrons) is given by:-

$$N_d = \left( \frac{I_d \cdot t_i}{q_e} \right)^{1/2}$$

where  $I_d$  is dark current,  $t_i$  is integration time in seconds and  $q_e$  is the charge on an electron in coulombs.

Talmi and Simpson [23] quote a value for  $N_d$  of 545 electrons rms at  $-20^\circ\text{C}$  for a 1 second integration time. This would give 5,450 electrons rms shot noise for 100 seconds integration time. As the full 14 pC saturation charge on a diode is equivalent to  $87.5 \times 10^6$  electrons, the dark current shot noise at  $-20^\circ\text{C}$  for 100 seconds is very small (0.000062 times the saturation charge). This is equivalent to 62  $\mu\text{V}$  noise on a 1 V signal or 3 times the least significant bit value of the AI13 analog to digital converter in the lowest (0 to 0.1 V) range. During the single array experiment, the lowest values of the readout noise were of the order of 1 mV at  $-28^\circ\text{C}$ . This is much greater than the dark current shot noise.

However, shot noise is not the only cause of dark current variation. Over long integration periods temperature variation is more important. Consider the temperature change  $\Delta T$  which would cause a dark current change equal to the readout noise  $N_d$ .

$$\Delta T = \frac{6.7 N_r}{t_i \cdot I_d \cdot \ln 2} \text{ in } ^\circ\text{C} \quad [23]$$

where  $N_r$  is in coulombs,  $t_i$  is integration time in seconds, and  $I_d$  is dark current. (The 6.7 and  $\ln 2$  terms refer to the doubling of dark current for a 6.7°C rise in temperature.)

At -20°C the dark current is 47 fA [23]. If the readout noise is 1 mV, equivalent to 87,500 electrons or  $1.4 \times 10^{-14}$  C, then  $\Delta T$  has a value of 0.029°C, for 100 s integration. The Peltier coolers have to pump down the array temperature by 34°C, so they have to have long term voltage stability of below 0.08% to maintain such temperature control.

The Peltier cooler is not an absolute cooler, it is simply a pump transferring heat from the array (and the atmosphere) to the cooling water.

Over several seconds of integration time, the temperature of the cooling water could be affected by other users of the same water supply. Furthermore, because it is heated by the Peltier coolers, any change in water pressure resulting in change in flow rate would result in a change in its effective temperature. A temperature change in the cooling water of more than 0.03°C appears quite probable for a series of measurements

taking several minutes. This may be a contribution to the increase in noise observed for the single array system as integration times were increased to 16 and 32 seconds (Table 7).

Vogt [25] also describes the generation of hole-electron pairs, and hence dark current, by power dissipation within the array chip during readout. This is another possible source of variation in the dark current although the change may not be significant with long integration times where the heat produced is not allowed to accumulate.

The noise generated by temperature changes is directly proportional to the time integrated dark current and would be reduced by operating the array at lower temperatures.

#### 8. Problems Caused by the Ribbon Cable

The layout of the RC1024S array drive boards meant that the arrays had to be run away from their drive boards. Twenty one of the array chip's pins are functional and must be connected to the drive board. The number of leads might have been reduced by 5 by combining common functions but this still leaves too many to handle by shielded cables yet still retain some freedom of movement for the array. Consequently a ribbon cable was

used. This was soldered to the back pins of the array socket on the array carriage and to a makeshift plug to fit into the onboard socket. Unfortunately the array is in the form of a 22 DIP chip and although 22 pin sockets were available, 22 pin DIP plugs were unobtainable. The 22 pin DIP chip is the only size of integrated circuit that has its 2 rows of pins separated by 0.4 inches. It was found that solder tail 22 pin sockets could act as plugs and these were used for the ribbon cables. They do not have the same conductor contact within the socket as one would expect from plugs.

Apart from the already described signal loss and cross-coupling of signals along the cable, there was some evidence of variability between even and odd diode signals depending on the position and degree of twist in the ribbon cable. This meant that the final tuning of the array circuitry had to be carried out after the array had been fixed in its correct position in the direct reader focal plane.

The ribbon cable is the weak link of the system and occurs at its most vulnerable spot, before the signals from the array have been amplified. It would be far better to replace the existing drive board and the ribbon cable with a redesigned printed circuit board carrying the array transversely at one end.

## 9. Problems Associated with the RC1024S Drive Board

When the drive board, modified as described in Chapter III, was used with the single array system, the only major problem experienced was the drifting of the odd-even diode balance with time. For a single array this was easy to follow and correct.

When all six arrays were running, several more serious defects were noticed. No two array systems were exactly alike. One system had an odd-even balance that varied too much to be useful. Another system had an unstable background level that prevented its use for integration times longer than 0.5 seconds. Another had an odd-even balance problem that affected the first few diodes only (Figures 50 and 51).

The variation in the DC background level was more than that which occurred with the single array system. This variation was often sufficient to move the signal of range of the analog to digital converter, especially when the latter was operating at the least input level setting.

An example of an oscillation occurring within the odd-even balance circuitry is shown in Figure 60. The oscillation was independent of the field of view and the start pulse level. It was observed that the oscillation

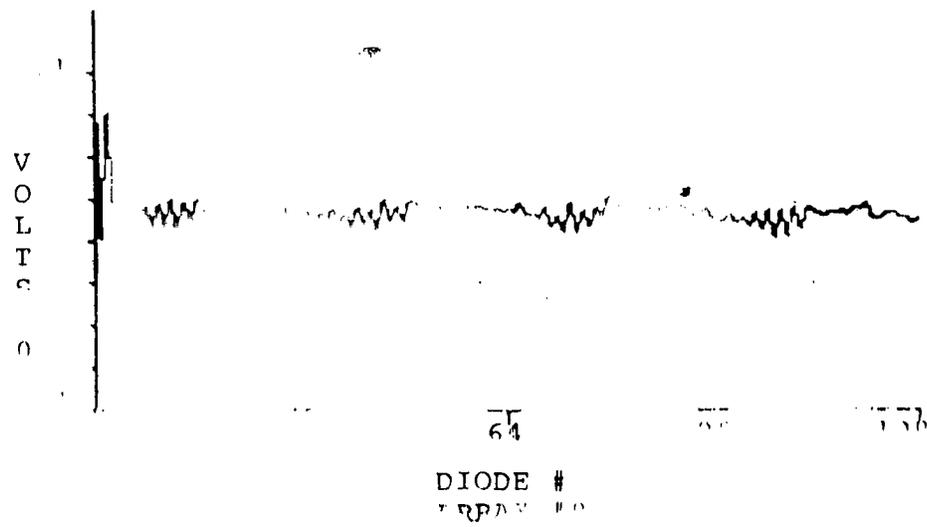
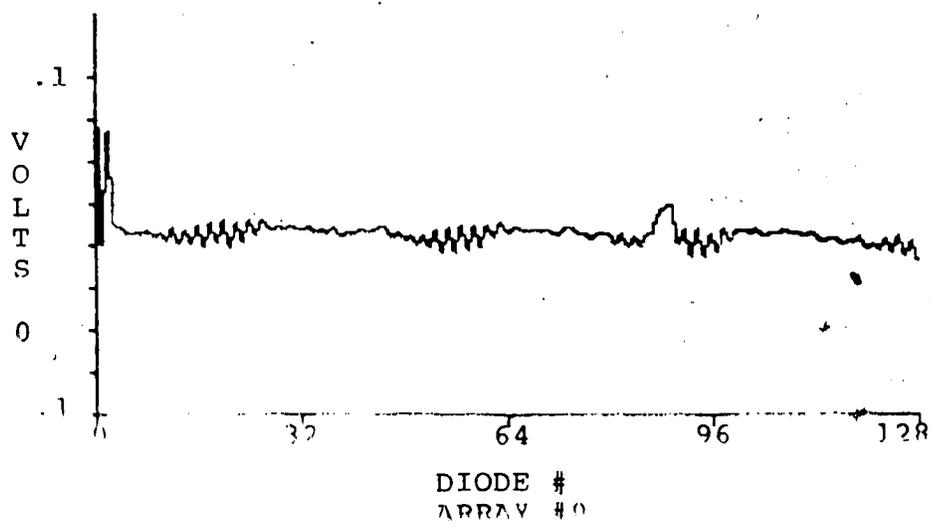


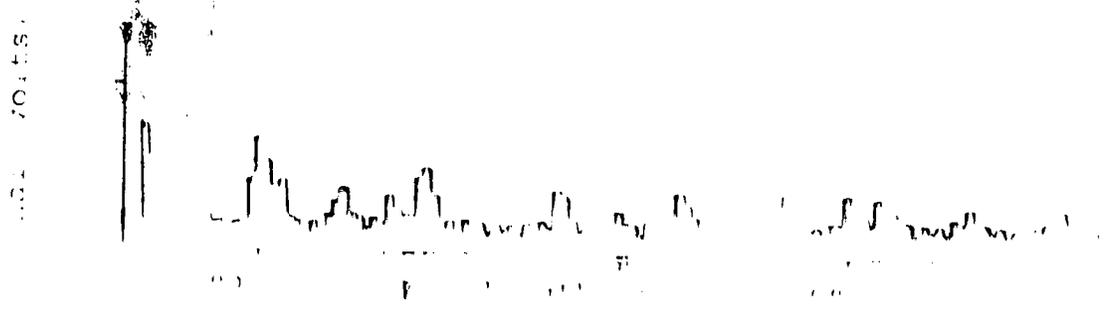
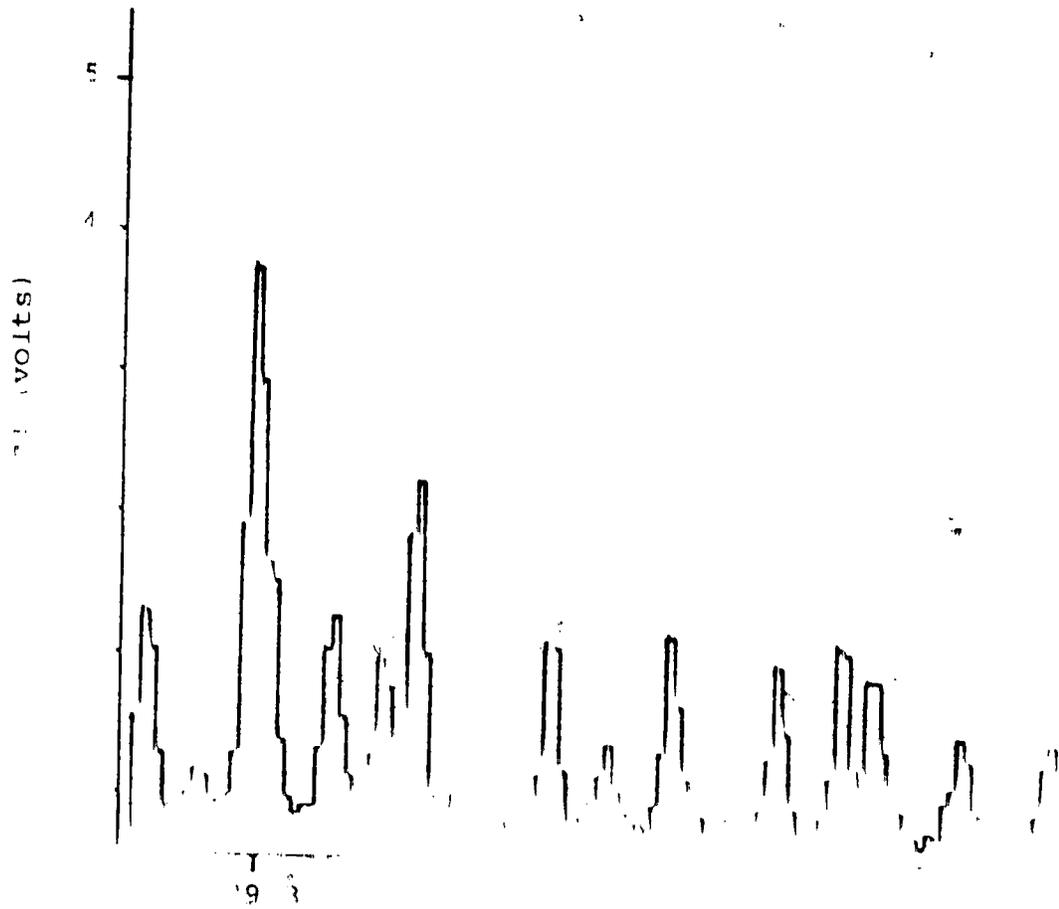
Figure 60. Data produced by oscillation in the

The major problem that arose was the frequently obtained excess in signal strengths at the output of the PC1024S board as illustrated by Figure 61. The odd-even balance appears to be unaffected which indicates that the signal gain occurred before the odd-even balance adjustment was applied.

The signal processing system is shown in Figure 61. The excess gain applies to both odd and even diodes a cause must apply equally to both halves of the signal processing circuitry. A power supply variation is a possibility. Alternatively, the signal change could be due to gross changes in the nebulizer throughput. This is highly unlikely but could be checked by the use of a purged nebulizer. Calculations for the gain of the signal favor the low values.

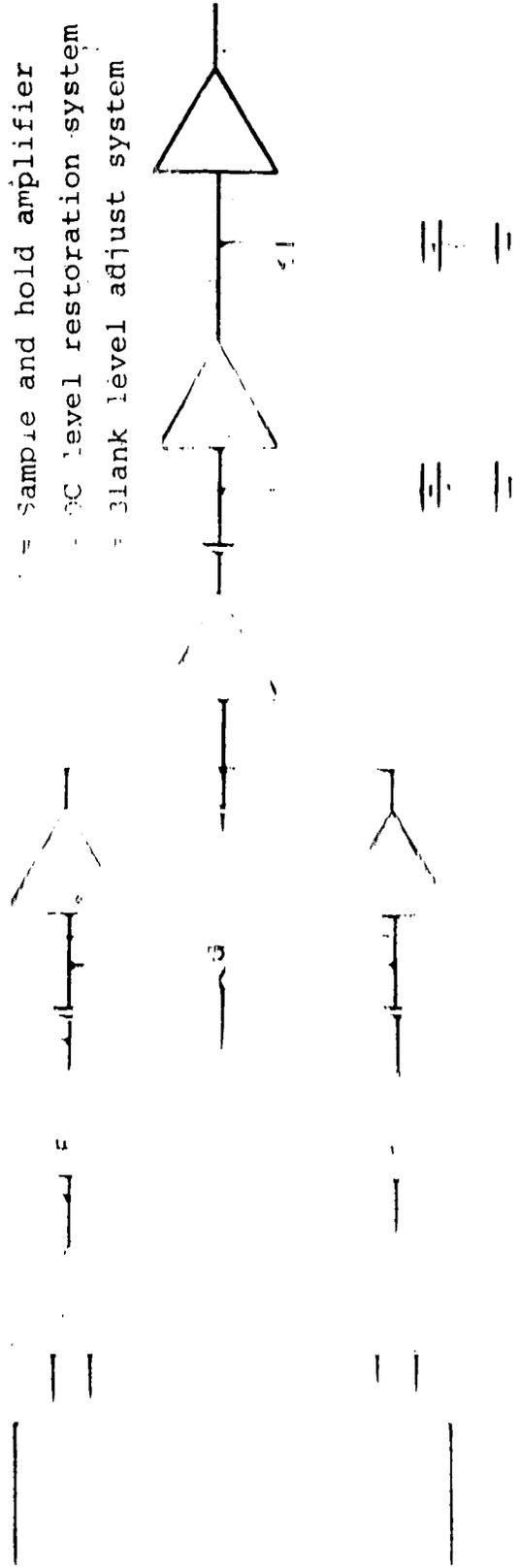
This problem presented the need of adjustment and allowed down the following of data. It had to be checked with the system by using a monitor which is not used for monitoring.

The test results, including the 6 runs, have been tested at the output of one of the boards. The results are shown in the table below. The test results show that the signal strength is not affected by the board used.



19 3

- code array
- DIFFERENCE AMPLIFIERS
- gain adjustment resistor
- preamplifier
- Odd-Even zero balance
- sample and hold amplifier
- DC level restoration system
- Blank level adjust system



REST.

Diagram of the signal processing circuit for a photodiode array.

superimposed at 10 kHz. The -15 V supply had a square wave pattern of 10 mV peak to peak at 10 kHz together with higher frequency background noise. The square wave disappeared when all the array systems but one were uncoupled from the power supply.

The direct reader system used three power supplies, excluding those used to drive the Peltier coolers. The system should be redesigned to run off a single power supply. In this respect it should be noted that there are significant differences in the ground levels of the electrical service outlets. For example, a 30 mV difference was measured across the ground wires of two outlets fed from the same circuit breaker.

The cause of the readout variations has not been established and further work is required.

#### 1. Precision Limitations of the System

The precision of one of the arrays in the six array system was determined from 10 measurements for a solution of 1.5 ppm copper. The results are given in Table 23. The background means and standard deviation for each determination were obtained from values of 8 off-peak diodes of the same odd-even character as the peak diode. The background standard deviations are approximately 1 mV, and the standard deviation for the single

Table 23. Measurements of precision for 1.5 ppm copper solution.

Peak Height V	Background Mean V	Background Std. Deviation	Signal/Noise
.01001	.05171	.00096	10.5
.00854	.04832	.00128	6.7
.00986	.05061	.00111	8.8
.00894	.05077	.00060	15.0
.00784	.05139	.00118	6.6
.00922	.05089	.00153	6.0
.00906	.05124	.00082	11.1
.0085	.0506	.00135	6.3
.00847	.05134	.00105	8.0
.0090	.05077	.00111	8.8

Mean peak height for 10 cups = 0.00922 V.

Standard deviation for 10 cups = 0.00111 V.

Ratio = 8.3

The signals from the spectral source, processed by the array and its drive board, are digitized by the analog to digital converter and stored by the computer. Measurements were made of the variability of the data acquisition system by grounding the input lines to the pre-amplifiers of the A113 analog to digital converter and recording the digitized values for 128 successive conversions for all 6 channels in use. The diode array sampling pulses were used to initiate the conversions. The effect of signal averaging was also determined. Results are summarized in Table 24. The least significant bit value for each A/DC setting is included for comparison.

As the signal averaging technique reduced the variability, the latter can be considered to be generally due to random noise. The variability for a single set of measurements, albeit for a large set, of about half a millivolt is approaching the variability for the overall signal measurement (Table 23). Consequently, any new design to improve the precision of the whole system must use a more stable A/D. There are 2 probable reasons for the A/D variations.

The A/D and the preamplifiers are powered by the Apple power supply which is involved in driving many other parts of the system and hence is very noisy.

Table 24. Variability of the A113 data acquisition system.

Standard deviations (V)				
A/DC range settings of				
Run Multiple	$\pm .1 \text{ V}$	$\pm .5 \text{ V}$	$\pm 1 \text{ V}$	$\pm 5 \text{ V}$
1	$4.95 \times 10^{-4}$	$8.79 \times 10^{-4}$	$2.98 \times 10^{-3}$	$2.76 \times 10^{-3}$
10	$2.59 \times 10^{-4}$	$2.57 \times 10^{-4}$	$9.39 \times 10^{-4}$	$1.11 \times 10^{-3}$
100	$7.17 \times 10^{-5}$	$1.21 \times 10^{-4}$	$3.49 \times 10^{-4}$	$1.16 \times 10^{-3}$
LSB	$4.88 \times 10^{-5}$	$2.44 \times 10^{-4}$	$4.88 \times 10^{-4}$	$2.44 \times 10^{-3}$

- ii. The analog signals are carried by a ribbon cable into the Apple case and the actual A/DC is not shielded against interference from the other electronic transitions occurring nearby.

In order to improve the precision for the same illumination of the grating, the noise levels must be reduced.

A 1 mV noise level is equivalent to one thousandth of the saturation signal of the array or 87,500 electrons rms. Simpson [31] has described the various noise sources for the S series of photodiode arrays. These are:-

- i. The photon shot noise of the incident light.
- ii. The shot noise of the dark current.
- iii. Preamplifier noise.
- iv. Reset noise of the diodes of the array.

Of these the photon shot noise is common to all detection systems.

The dark current shot noise has already been discussed. It has rms values of  $5,600 \times \sqrt{t_i}$  at 25°C and  $545 \sqrt{t_i}$  at -20°C where  $t_i$  is integration time in seconds [23].

The diode reset or thermodynamic noise  $n_r$  is given by [31]

$$n_r = \left(\frac{1}{q_e}\right) [kT(2C_p + 2C_{vc})]^{1/2}$$

where  $k$  is the Boltzmann Constant,  $T$  is absolute temperature,  $C_p$  is the diode capacitance,  $C_{vc}$  is video line to clock line capacitance and  $q_e$  is the charge on the electron.

Simpson quotes a value of 1000 electrons rms for  $n_r$  at 25°C for a 1024 diode array.

The preamplifier noise is given by [31]

$$n_a = \left(\frac{1}{q_e}\right) [(i_n t_p)^2 + (e_n C)^2]^{1/2}$$

where  $i_n$  is the preamplifier noise current,  $e_n$  is the preamplifier input noise voltage,  $C$  is capacitance at the amplifier input and  $t_p$  is the time to read a diode.

Simpson states: "With the proper choice of input device and circuit design,  $n_a$  can be reduced below the thermodynamic noise." That is to say below 1000 electrons rms.

Thus the total noise for dark current and readout could be as low as

$$n_T = (10^6 + 10^6 + 31 \times 10^6 \cdot t_j)^{1/2} \text{ at } 25^\circ\text{C}$$

This gives  $n_T$  equal to 5.775 electrons rms for a 1 second integration and 55.695 electrons for a 100 second

integration. At  $-20^{\circ}\text{C}$  a 100 second integration time could have a noise level as low as 5,620 electrons rms. The direct reader system has 87,500 electrons rms noise. Unlike the systems described by Simpson, the direct reader noise is limited by readout noise, not the dark current shot noise. The designers of the RC1024S have taken care to limit the distance between the array and the preamplifier as the equations for both the thermodynamic noise and the preamplifier noise contain capacitance terms. Clearly no great improvement in the precision of the diode array direct reader can be expected until the ribbon cable is replaced by a redesigned drive card.

Several discussions of low noise amplifiers for diode arrays can be found in the published literature [25,26,31,58].

#### 11. Processing Delays Caused by Program Loading

The software to run the direct reader system was written and operated in sections to suit the experimental nature of the system. The Apple disk operating system is designed so that the disk drives are normally off. This is done to save wear. However, there is some delay caused by the system requiring time to start up. During the development of the direct reader, the operation of the disk drives has been a useful diagnostic tool.

For a routine operating system, a faster running system would be preferred. The overall speed of operation could be improved in several ways:-

- i. All machine code programs could be located in the 16K language card and called when required. In order to save loading them at every start up they could be loaded onto a read only memory chip which is then fitted to the language card.
- ii. Basic programs used sequentially could be combined. Programs can be shortened by leaving out REM statements, combining lines and becoming less user friendly.
- iii. Faster running disk operating systems are available.
- iv. Some of the BASIC routines such as multiplication and division could be duplicated in machine code and loaded into the language card.

The problems associated with the diode array direct reader are considerable but all are capable of solution. They are worth solving because the potential of the instrument is considerable. Photodiode array detectors are already in use as full spectrum detectors for ultra violet and visible molecular absorption spectroscopy [59]. Their application in commercial instruments for atomic emission spectroscopy is overdue.

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70. Apple II 6502 Assembler, Apple Computer Inc.

APPENDIX 1



- 15 psi (Chapter VI)

- iv. Auxiliary gas - .8 lpm (Chapter IV)
- .4 lpm (Chapter VI)
- .6 lpm (Chapter VI)

APPENDIX 2

## APPENDIX 2

### MODIFICATION OF THE RC1024S CIRCUIT BOARD

#### A. • Join Edge Tab 6 to Edge Tab F

Tab 6 carries the odd diode series end of line signal (Diode 127 has been read). Pin 6 on the 44 pin edge connector interfered with the firm attachment of the coaxial cable carrying the output signal from the board. Pin 6 was then removed from the edge connector leaving the odd EOL signal available on pin F.

#### B. Change Capacitor C<sub>1</sub>

Capacitor C<sub>1</sub> is a timing capacitor in the oscillator. It was changed from 500 pf to 0.005  $\mu$ f to reduce the diode sampling rate range from 37.5-150 kHz to 4-62.5 kHz.

#### C. Connect Edge Tab W to OR'd Sampling Pulse

Pins 9, 10, 11 of U30 (7400) on the board carry the OR'd odd and even sampling pulse signals. - The signal was wired to edge tab W so that it could be used elsewhere as a data acquisition control signal.

D. Rewire Pin 3 on 7474 Flip-Flop

Flip-flop U11 (7474) is the start pulse controller. The printed circuit lead to pin 3 was cut to isolate it from the onboard timing chain. It was wired to edge tab R to connect it to the off board start pulse generator.

E. Isolate the Oscillator

The output of the oscillator was isolated from the rest of the circuit so that it could be gated. The printed circuit was cut between pin 5 on U1 (9602) and pin 1 on U6 (7404). It also separated it from pin 2 on U2 (74161), the first counter in the timing chain. The oscillator signal was already connected to edge tab U for connection to the gate.

F. Join Edge Tab P to U2 and U6

The gated oscillator signal was brought back to the board through edge connector P and hence to pin 1 on U6 (7404) and pin 2 on U2 (74161).

G. Remove the Last Onboard Counter

U5 (74161) the fourth 16 bit counter was replaced by a socket to connect to the timing chain extension. When external start pulses were introduced, the unused socket was bypassed by connecting its controlling enable pin to its overflow pulse pin (Pin 10 to pin 15).

H. Join Edge Tab M to Pin 5 of 7474 Flip-Flop

Pin 5 of U11 (7474) puts out the start pulse signal to the array. It was wired to edge tab M so that both the rising and falling edges of the start pulse were available as data acquisition control signals.

APPENDIX 3



APPENDIX 3

INTERFACE BETWEEN THE AIM 65 AND THE 1131J A/DC

AC 1580 CONNECTOR	
LINE	EDGE TAB
BIT 13	2
LSB (14)	3
TTY 14	4
TTY 10	5
TTY 5	6
TTY 1	7
START PULSE	13
DIGITAL GROUND	15
GROUND	22
MSB (1)	A
BIT 2	B
BIT 3	C
BIT 4	D

AIM 65 J1 CONNECTOR	
EDGE TAB	LINE
4	PA1
14	PA0
R	TTY KBD RETURN
S	TTY PTR RETURN
T	TTY KBD
U	TTY PTR
18	CBI
1	GROUND
1	GROUND
16	PB5
13	PB4
12	PB3
11	PB2

AC 1580 CONNECTOR	
LINE	EDGE TAB
BIT 5	E
BIT 6	F
BIT 7	H
BIT 8	J
BIT 9	K
BIT 10	L
BIT 11	M
BIT 12	N
MIKE SOCKET	W
EAR SOCKET	X
STATUS	Z

AIM 65 J1 CONNECTOR	
EDGE TAB	LINE
10	PB1
9	PB0
8	PA7
7	PA6
6	PA5
5	PA4
2	PA3
3	PA2
M	AUDIO OUT
L	AUDIO IN
20	CA1

CONVERT	V
COMMAND	

DATA ACQUISITION
CONTROL SIGNAL

APPENDIX 4

## APPENDIX 4

### AIM 65 PROGRAMS

The data acquisition program LOG1 collects the 14 bit data values for 128 diodes. It gives the option of signal averaging by adding consecutive sets of data and then dividing by the number of sets added. It has the option of subtracting the same number of sets of data for a selected background condition. The machine code part of the program sets the data storage addresses to zero and then idles while it waits for a start pulse. It then logs data on receipt of a conversion completed signal from the analog to digital converter. Three 8 bit bytes are used for each diode: a 12 bit, a high byte and an overflow or zero byte. The data bytes are stored in memory. The data bytes are

```

10  REM **AIM 65 PROGRAMME LOG1**
25  REM COLLECT DATA FROM A SINGLE ARRAY OF 128 DIODES WITH SIGNAL AVERAGING
30  REM AND OPTIONAL BACKGROUND SUBTRACTION
40  PRINT "BACKGROUND SUBTRACTED ? Y=1,N=0"
50  O = 128:J = 3712:K = J + 0:L = K + 0:M = 2 * 0:F = 234:W = 1:G = 0
60  F = 0 * 0
70  REM J,K,L ARE BASE ADDRESSES FOR STORAGE OF LOW,HIGH, ARRAY BY ER
80  REM F=234=EA=NO OPERATION TO CANCEL THE INSTRUCTION TO THE
90  REM IN LINE 130
100 INPUT A
110 IF A = 1 THEN 150
120 POKE 1710,76: POKE 1711,5: POKE 1712,7
130 REM THIS FORCES A JUMP TO THE END OF THE PROGRAMME
140 GOTO 160
150 POKE 1710,F: POKE 1711,7: POKE 1712,7
160 PRINT "4 OF 128"
170 INPUT B
180 POKE 3711,B: POKE 4,8: POKE 6,6
190 REM MACHINE CODE FOR FALL THROUGH TO ADDRESS 1710
200 = USR (1) REM CODE FOR FALL THROUGH TO ADDRESS 1710
210 FOR N = 0 TO 127
220 = FFEK (J + N) D *
230 PRINT "0 10"
240 REM INT
250 NEXT N

```

SOURCE FILE: MLOG1

0000: 1 \*MACHINE LANGUAGE PROGRAMME FOR AIM 65 DATA LOGGING WITH  
 0000: 2 \*BACKGROUND SUBTRACTION OPTION

----- NEXT OBJECT FILE NAME IS MLOG1.OBJ0

```

0650:          3      ORG    $0650
0650:D8          4      CLD
0651:78          5      SEI
0652:A2 7F      6      LDX    $$7F      ;LOAD DATA MEMORY SPACE
0654:A9 00      7      LDA    $$00      ;WITH ZERO'S
0656:9D 80 0E   8      STA    $0E80,X
0659:9D 00 0F   9      STA    $0F00,X
065C:9D 80 0F  10     STA    $0F80,X
065F:CA          11     DEX
0660:10 F4      12     BPL    BR1
0662:EA          13     NOP
0663:AC 7F 0E   14     LDY    $0E7F      ;# OF RUNS TO BE AVERAGED
0666:A9 00      15     LDA    $$00
0668:BD 0C A0   16     STA    $A00C      ;PCR SETS IFR FOR -1 TO 0 STEP
066B:AD 00 A0   17     LDA    $A000      ;CLEAR IFR BITS 3 & 4
066E:AD 0D A0   18     BR2    LDA    $A00D      ;CHECK IFR FOR FLAG ON
0671:29 10      19     AND    $$10      ;BIT 4 (CB1) START PULSE
0673:F0 F9      20     BEQ    BR2
0675:AD 00 A0   21     LDA    $A000      ;CLEAR IFR BIT 4
0678:AD 01 A0   22     LDA    $A001      ;CLEAR IFR BITS 0 & 1
067B:A9 00      23     LDA    $$00      ;SET DDRA AND DDRB
067D:BD 03 A0   24     STA    $A003      ;SO DRA AND DRB ARE
0680:BD 02 A0   25     STA    $A002      ;ALL INPUTS
0683:A2 7F      26     LDX    $$7F      ;SET COUNTER FOR 128 DIODES
0685:AD 0D A0   27     LDA    $A00D      ;SEARCH FOR CLOCK PULSE
0688:29 02      28     AND    $$02
068A:F0 F9      29     BEQ    BR3
068C:AD 01 A0   30     LDA    $A001      ;READ LOWEST 8 BITS OF DATA
068F:7D 80 0E   31     ADC    $0E80,X      ;ADD IT TO THE DATA
0692:9D 80 0E   32     STA    $0E80,Y      ;ALREADY COLLECTED
0695:AD 00 A0   33     LDA    $A000      ;READ HIGHEST BITS OF DATA
0698:29 3F      34     AND    $$3F      ;CLEAN OFF THE TWO MSB'S
069A:7D 00 0F   35     ADC    $0F00,X      ;ADD IT TO THE DATA
069D:9D 00 0F   36     STA    $0F00,X      ;ALREADY COLLECTED
06A0:ED 80 0F   37     LDA    $0FB0,X      ;READ THE CARRY FILE
06A3:69 00      38     ADC    $$00      ;ADD THE NEW CARRY IF PRESENT
06A5:9D 80      39     STA    $0F00,X      ;UPDATE THE CARRY FILE
06A8:CA          40     DEX
06A9:10 00      41     BPL    BR2
06AB:88          42     DEY
06AC:EA          43     NOP
06AD:D0 BF      44     BNE    BR2
06AF:10 04 0F   45     JMP    BR2
06B2:          46
06B2:00          47     BRK
06B3:AC 7F 0F   48     LDY    $0E7F      ;TIME TO TAKE BACKGROUND DATA
06B6:A9 00      49     LDA    $$00      ;SET UP REPLICATE COUNTER
06B8:BD 0C A0   50     STA    $A00C      ;PCR SETS IFR FOR 1 TO 0 STEP
06BB:AD 00 A0   51     LDA    $A000      ;CLEAR IFR BITS 3 & 4
06BE:AD 0D A0   52     LDA    $A00D      ;CHECK IFR FOR FLAG ON
06C1:29 10      53     AND    $$10      ;BIT 4 (CB1) START PULSE
06C3:F0 F9      54     BEQ    BR4
06C5:AD 00 A0   55     LDA    $A000      ;CLEAR IFR BITS 3 & 4
06C8:AD 01 A0   56     LDA    $A001      ;CLEAR IFR BITS 0 & 1
06CB:A9 00      57     LDA    $$00      ;SET DD'A AND DDRB
  
```

06D0:BD 02 A0	59	STA	\$A002	;ALL INPUTS
06D3:A2 7F	60	LDX	##7F	;SET COUNTER FOR 128 DIODES
06D5:AD 0D A0	61	LDA	\$A00D	;SEARCH FOR CLOCK PULSE
06D8:29 02	62	AND	##02	;ON BIT 1 (CA1)
06DA:F0 F9	63	BEO	BR5	
06DC:38	64	SEC		;SET CARRY FLAG FOR SUBTRACTION
06DD:BD 80 0E	65	LDA	\$0E80,X	;FETCH DATA FROM FILE
06E0:ED 01 A0	66	SEC	\$A001	;SUBTRACT BACKGROUND (LOW 8 BITS)
06E3:9D 80 E0	67	STA	\$E080,X	;UPDATE FILE
06E6:BD 00 A0	68	LDA	\$A000,X	;READ HIGHEST BITS OF BACKGROUND
06E9:29 3F	69	AND	##3F	;CLEAN OFF THE TWO MSB'S
06EB:8D 7E 0E	70	STA	\$0E7E	;PUT IN TEMPORARY FILE
06EE:BD 00 0F	71	LDA	\$0F00,X	;FETCH DATA FROM FILE
06F1:ED 7E 0E	72	SEC	\$0E7E	;SUBTRACT TEMPORARY FILE
06F4:9D 00 0F	73	STA	\$0F00,X	;UPDATE FILE
06F7:BD 80 0F	74	LDA	\$0FB0,X	;FETCH CARRY FILE
06FA:E9 00	75	SEC	#00	;SUBTRACT CARRY IF STILL SET
06FC:BD 80 0F	76	STA	\$0FB0,X	;UPDATE FILE
06FF:CA	77	DEX		;DECREMENT THE DIODE COUNTER
0700:10 D3	78	BFL	BR5	;READ ANOTHER DIODE ?
0702:88	79	DEY		;DECREMENT REPLICATE COUNTER
0703:EA	80	NOP		
0704:D0 FB	81	BNE	BR5	;READ WHOLE ARRAY AGAIN ?
0704:60	82	FINISH	RTS	;GO BACK TO BASIC PROGRAMME

The signal to noise ratio program, SNR03, logs the data points for 32 diodes 32 times, and stores each acquisition separately. This takes 2048 bytes of memory for storage (2 bytes per data point). It then calculates the mean, standard deviation and the ratio as the signal to noise ratio for each of the 32 diodes and prints them out. It then allows the subtraction from the individual data values of 32 values for 32 diodes for a selected background condition. It then recalculates the subtracted mean, standard deviation and signal to noise ratio, and prints them out.

The diode numbers on the print out are for the position of the diode within those logged, not its position on the array.

The machine code program first converts the identity of the diodes to be logged into a series of numbers corresponding to the size of groups of diodes to be omitted or recorded. It makes extensive use of subroutines and indirect indexed addressing. It was this program in its background subtraction mode that set the limiting speed of data acquisition.

Getting this program and its data storage space into the available space on the AIM 65 was difficult.

```

10 REM **AIM 65 PROGRAM**SNR03
20 REM SIGNAL/NOISE RATIO FOR A 128 DIODE ARRAY (WITH BACKGROUND SUBTRACTION)
30 REM A TOTAL OF 32 DIODES IN UP TO 4 GROUPS ARE LOGGED 32 TIMES AND MEAN, STD
35 REM DEVIATION AND SIGNAL TO NOISE RATIO PRINTED OUT
40 REM *THE STARTING DIODE #'S MUST BE IN NUMERICAL ORDER
50 DIM A(7): PRINT "1ST, #, 4TIMES, MAX32": POKE 4,166: POKE 5,6: B = 2048
60 REM THE # OF THE 1ST DIODE IN A GROUP AND THE # OF DIODES IN THAT GROUP
70 REM IS ENTERED(TOTAL DIODES 32)
80 C = 2040: D = 32: INPUT A(0),A(1),A(2),A(3),A(4),A(5),A(6),A(7)
90 E = SQR (31): F = 992: G = 3072: H = 256: AA = 16383: BE = H * H
100 FOR I = 0 TO 7: POKE C + I, A(I): NEXT I: J =USR (K)
110 REM LOADS DIODE NUMBERS TO ADDRESSES $07FB TO $07FF
120 IF PEEK (2039) = 1 GOTO 150
130 REM THIS IS A M/C TEST FOR INPUT ERROR
140 PRINT "INPUT WRONG": GOTO 50
150 FOR M = 0 TO 31: N = M + 1: O = 0: P = 0
160 FOR Q = 0 TO F STEP D: R = Q + M: S = PEEK (B + R): T = PEEK (G + R): U = T *
H + S
170 IF AA < U THEN U = - (BE - U)
175 REM THIS CORRECTS FOR VALUE BEING NEGATIVE AFTER THE SUBTRACTION
180 V = U * U: O = O + U: P = P + V: NEXT Q
190 X = O / D: Y = SQR (P - O * O / D) / E: PRINT N: X / Y: X * 5 / (D * H): Y * 5
/ (D * H)
195 REM PRINTS OUT SNR, MEAN AND STD DEVIATION FOR EACH DIODE SELECTED
197 REM *CAUTION THE DIODE # IN THE PRINT OUT GIVES IT'S POSITION WITHIN THOSE
198 REM LOGGED, NOT IT'S POSITION ON THE ARRAY
200 NEXT M
210 IF PEEK (2038) = 0 GOTO 260
220 POKE 2038, 0
230 POKE 4,117: POKE 5,7
240 JJ = USR (KK)
250 GOTO 150
260 PRINT "DONE ? Y=1,N=0": INPUT Z
270 IF Z = 0 THEN 50
280 STOP

```

SOURCE FILE: MSNR03

----- NEXT OBJECT FILE NAME IS MSNR03.OBJ0

```

0620:          1          ORG    $0620
0620:          2 *MACHINE LANGUAGE PROGRAM FOR AIM 85.
0620:          3 *TO COLLECT DATA FOR 32 DIODES 32 TIMES AND STORE ALL VALUES
0620:          4 *SEPARATELY. ALSO HAS BACKGROUND SUBTRACTION OPTION
0620:          5 *
                                SUBROUTINE#1 COUNT UNLOGGED DIODES
0620:AD 0D A0      6 BR1      LDA    $A00D
0623:29 02      7          AND    $02
0625:F0 F9      8          BEQ    BR1
0627:AD 01 A0      9          LDA    $A001
062A:60          10         RTS
062B:EA          11         NOP
062C:EA          12         NOP
062D:EA          13         NOP
062E:          14 *
                                SUBROUTINE#2 LOG DATA VALUES
062E:AD 0D A0     15 BR2      LDA    $A00D
0631:29 02     16          AND    $02
0633:F0 F9     17          BEQ    BR2
0635:AD 01 A0     18          LDA    $A001 ;READ VALUE LOW BYTE
0638:91 F0     19          STA    ($F0),Y
063A:AD 00 A0     20          LDA    $A000 ;READ VALUE HIGH BYTE
063D:29 3F     21          AND    $3F ;CLEAN OFF UNWANTED BITS
063F:91 F2     22          STA    ($F2),Y
0641:60          23         RTS
0642:EA          24         NOP
0643:EA          25         NOP
0644:EA          26         NOP
0645:          27 *
                                SUBROUTINE#3 LOG AND SUBTRACT
0645:          28 *                                BACKGROUND VALUES
0645:AD 0D A0     29 BR3      LDA    $A00D
0648:29 02     30          AND    $02
064A:F0 F9     31          BEQ    BR3
064C:38          32         SEC
064D:E1 F0     33          LDA    ($F0),Y
064F:ED 01 A0     34          SEC    $A001
0652:91 F0     35          STA    ($F0),Y
0654:AD 00 A0     36          LDA    $A000
0657:29 03     37          AND    $3F
0659:BD F5 07     38          STA    $07F5
065C:E1 F2     39          LDA    ($F2),Y
065E:ED F5 07     40          SEC    $07F5
0661:91 F2     41          STA    ($F2),Y
0663:60          42         RTS
0664:EA          43         NOP
0665:EA          44         NOP
0666:EA          45         NOP
0667:          46 *
0667:          47 *
0667:DB          48 BR5      CLD
0668:18          49          CLC
0669:A5 F0          50          LDA    $F0
066B:69 20          51          ADC    $20
066D:85 F0          52          STA    $F0
066F:A5 F1          53          LDA    $F1
0671:69 00          54          ADC    $00
0673:85 F1          55          STA    $F1
0675:18          56          CLC
0676:A5 F2          57          LDA    $F2
0678:69 20          58          ADC    $20

```

```

067A:85 F2      59      STA  $F2
067C:A5 F3      60      LDA  $F3
067E:69 00      61      ADC  #$00
0680:85 F3      62      STA  $F3
0682:CA         63      DEX
0683:60         64      RTS
0684:EA         65      NOP
0685:EA         66      NOP
0686:EA         67      NOP
0687:         68 *
0687:A2 20      69 BR6  LDX  #$20
0689:A9 00      70      LDA  #$00
068B:85 F0      71      STA  $F0
068D:85 F2      72      STA  $F2
068F:A9 08      73      LDA  #$08
0691:85 F1      74      STA  $F1
0693:A9 0C      75      LDA  #$0C
0695:85 F3      76      STA  $F3
0697:A9 00      77      LDA  #$00
0699:8D 0C A0   78      STA  $A00C
069C:         79 *
069C:8D 02 A0   80      STA  $A002
069F:8D 03 A0   81      STA  $A003
06A2:80         82      RTS
06A3:EA         83      NOP
06A4:EA         84      NOP
06A5:EA         85      NOP
06A6:DB         86      CLD
IC
06A7:78         87      SEI
06A8:AD FE 07   88      LDA  $07FE
06AB:38         89      SEC
06AC:ED FD 07   90      SBC  $07FD
06AF:38         91      SEC
06B0:ED FC 07   92      SBC  $07FC
06B3:8D FE 07   93      STA  $07FE
06B6:90 2B      94      FCC  BR1
06B8:         95
06B8:AD FC 07   96      LDA  $07FC
06BE:38         97      SEC
06BC:ED FB 07   98      SBC  $07FB
06BF:38         99      SEC
06C0:ED FA 07  100     SBC  $07FA
06C3:8D FC 07  101     STA  $07FC
06C6:90 1B      102     FCC  BR1
06CB:         103
06CB:AD FA 07  104     LDA  $07FA
06CE:38         105     SEC
06CC:ED F9 07  106     SBC  $07F9
06CF:38         107     SEC
06D0:ED FB 07  108     SBC  $07FB
06D3:8D FA 07  109     STA  $07FA
06D6:90 0B      110     FCC  BR1
06DB:         111
06DB:A9 01      112     LDA  #$01
06DA:8D F7 07  113     STA  $07F7
06DD:8D F6 07  114     STA  $07F6
06E0:         115
06E0:4C EB 06  116     JMP  NOERR
06E3:A9 00      117     LDA  $0000

```

```

SUBROUTINE#5 SET UP BASE ADDRESSES
;SET FOR 32 CYCLES

```

```

;LOW BYTE BASE ADDRESS #0800
;HIGH BYTE BASE ADDRESS #0C00

```

```

;SET PCR FOR INTERRUPT ON A 1 TO 0
TRANSITION
;SET ORA AND ORE AS TRIGGERS

```

```

;ENTRY POINT INTO THE PROGRAM FROM BAS

```

```

;THIS PART OF THE PROGRAM TESTS FOR
;ERRORS IN INPUT BY ENSURING THAT NO
;DIODE BELONGS TO MORE THAN ONE GROUP
;THAT IS TO BE LOGGED

```

```

;THIS IS THE # OF DIODES TO BE IGNORED
;BETWEEN THE 3'D AND 4TH GROUPS TO BE
;LOGGED. THIS IS THE FIRST GROUP

```

```

;THIS IS THE # OF DIODES TO BE IGNORED
;BETWEEN THE 1ST AND 2ND GROUPS TO BE
;LOGGED

```

```

;THIS IS THE # OF DIODES TO BE IGNORED
;BETWEEN THE 1ST AND 2ND GROUPS TO BE
;LOGGED

```

```

;THIS THE SIGNAL FOR ER OR RELE THE
;THIS IS THE SIGNAL FOR THE

```

```

06E8:4C EB 07 119 JMP FINISH ;GO BACK TO BASIC PROGRAM AND RE-ENTER
06EB: 120 * INPUT
06EB:1B 121 NOERROR CLC
06EC:EA 122 NOP
06ED:EA 123 NOP
06EE:EA 124 NOP
06EF:AD F9 07 125 LDA $07F9 ;THIS SECTION ADDS AND STORES DIODE
06F2:6D FB 07 126 ADC $07FB ;GROUP TOTALS
06F5:8D FB 07 127 STA $07FB
06F8:6D FD 07 128 ADC $07FD
06FB:8D FD 07 129 STA $07FD
06FE:6D FF 07 130 ADC $07FF
0701:8D FF 07 131 STA $07FF
0704:CE F8 07 132 DEC $07FB ;THIS GIVES THE # OF THE LAST DIODE
0707: 133 * TO BE IGNORED AT THE START OF THE
0707: 134 * ARRAY SCAN
0707:20 B7 06 135 JSR BR6
070A:AD 00 A0 136 BR18 LDA $A000 ;CLEAR IFR
070D:AD 0D A0 137 BR7 LDA $A00D ;LOOK FOR START PULSE
0710:29 10 138 AND $10
0712:F0 F9 139 BEQ BR7 ;NOT FOUND IT YET ?
0714:AD 00 A0 140 LDA $A000 ;CLEAR IFR
0717:AC FB 07 141 LDY $07FB ;LOAD # OF LAST DIODE TO BE IGNORED AT
071A: 142 * START OF SCAN
071A:F0 0B 143 BEQ BR10 ;IF 0 START LOGGING DATA
071C:20 20 06 144 BR9 JSR BR1 ;COUNT OF 1ST SET OF UNWANTED DIODES
071F:8B 145 DEY
0720:D0 FA 146 BNE BR9
0722:A0 00 147 LDY $000 ;ZERO COUNTER FOR 1ST SET OF LOGGED
0724: 148 * DIODES
0724:20 2E 06 149 BR10 JSR BR2 ;LOG A DIODE VALUE
0727:C8 150 INY ;COUNT IT
0728:CC F9 07 151 CPY $07F9 ;ARE THEY ALL DONE ?
072E:90 F7 152 BCC BR10 ;IF NOT LOG ANOTHER ONE
072D:AC FA 07 153 LDY $07FA ;LOAD COUNTER WITH # OF DIODES TO BE
0730: 154 * IGNORED
0730:20 20 06 155 BR11 JSR BR1 ;COUNT OF 2ND SET OF UNWANTED DIODES
0733:8B 156 DEY
0734:D0 FA 157 BNE BR11
0736:AC F9 07 158 LDY $07F9 ;START THE COUNTER HERE FOR THE 2ND
0739: 159 * GROUP OF DIODES TO BE LOGGED
0739:20 2E 06 160 BR17 JSR BR2 ;LOG A DIODE VALUE (2ND SET)
073C:C8 161 INY ;COUNT IT
073D:CC FB 07 162 CPY $07FB ;DONE ?
0740:90 F7 163 BCC BR12 ;IF NOT LOG ANOTHER
0742:AC FC 07 164 LDY $07FC ;LOAD COUNTER WITH # OF DIODES TO BE
0745: 165 * IGNORED
0745:20 20 06 166 BR13 JSR BR1 ;COUNT UNWANTED DIODES
0748:8B 167 DEY
0749:D0 FA 168 BNE BR13
074B:AC FB 07 169 LDY $07FB ;START COUNTER HERE FOR 3RD GROUP OF
074E: 170 * DIODES TO BE LOGGED
074E:20 2E 06 171 BR17 JSR BR2 ;LOG A DIODE VALUE (3RD SET)
0751:C8 172 INY ;COUNT IT
0752:CC FD 07 173 CPY $07FD ;DONE ?
0755:90 F7 174 BCC BR14 ;IF NOT LOG ANOTHER
0757:AC FE 07 175 LDY $07FE ;LOAD COUNTER WITH # OF DIODES TO BE
075A: 176 * IGNORED
075A:20 20 06 177 BR17 JSR BR1 ;COUNT UNWANTED DIODES
075D: 178 *

```

```

075E:D0 FA 179 BNE BR15
0760:AC FD 07 180 LDY $07FD ;START COUNTER HERE FOR 4TH GROUP OF
0763: 181 * DIODES TO BE LOGGED
0763:20 2E 06 182 BR16 JSR BR2 ;LOG A DIODE VALUE (4TH SET)
0766:CB 183 INY ;COUNT IT
0767:CC FF 07 184 CPY $07FF ;DONE ?
076A:90 F7 185 BCC BR16 ;IF NOT LOG ANOTHER
076C:20 67 06 186 JSR BR5 ;CHANGE ADDRESSES OF THE DATA STORAGE
076F: 187 * REGISTERS FOR THE NEXT SET OF DATA
076F:F0 03 188 BEQ BR17 ;IF ANALYTE DATA COLLECTION COMPLETE
0771: 189 * STOP AND GO BACK TO BASIC TO SET UP
0771: 190 * FOR BACKGROUND DATA COLLECTION
0771:4C 0A 07 191 JMP BR18 ;IF LESS THAN 32 SCANS GO ROUND AGAIN
0774:60 192 BR17 RTS
0775:00 193 BRK ;THIS IS THE ENTRY POINT FROM BASIC
0776: 194 * FOR THE BACKGROUND SUBTRACTION
0776:EA 195 NOP
0777:EA 196 NOP
0778:20 87 06 197 JSR BR6 ;INITIALISE FOR BACKGROUND SUBTRACTION
077E:AD 00 A0 198 BR19 LDA $A000 ;CLEAR IFR
077E:AD 0D A0 199 BR20 LDA $A00D ;LOOK FOR START PULSE
0781:29 10 200 AND $10 ;ON CONTROL LINE CB1
0783:F0 F9 201 BEQ BR20 ;CAN'T FIND IT KEEP LOOKING
0785:AD 00 A0 202 LDA $A000 ;CLEAR IFR
0788:AC FB 07 203 LDY $07FB ;LOAD # OF LAST DIODE TO BE IGNORED AT
078E: 204 * THE START OF THE SCAN
078E:F0 08 205 BEQ BR23 ;IF 0 START LOGGING DATA
078D:20 20 06 206 BR22 JSR BR1 ;COUNT OF 1ST SET OF UNWANTED DIODES
0790:88 207 DEY
0791:D0 FA 208 BNE BR22
0793:A0 00 209 LDY $00 ;ZERO COUNTER FOR 1ST SET OF LOGGED
0795: 210 * DIODES
0795:20 45 06 211 BR23 JSR BR3 ;LOG AND SUBTRACT BACKGROUND DATA
0798:CB 212 INY ;COUNT
0799:CC F9 07 213 CPY $07F9 ;DONE ?
079C:90 F7 214 BCC BR23 ;IF NOT DO IT AGAIN
079E:AC FA 07 215 LDY $07FA ;LOAD COUNTER WITH # OF DIODES TO BE
07A1: 216 * IGNORED
07A1:20 20 06 217 BR24 JSR BR1 ;COUNT UNWANTED DIODES
07A4:88 218 DEY
07A5:D0 FA 219 BNE BR24
07A7:AC F9 07 220 LDY $07F9 ;START THE COUNTER HERE FOR THE 2ND
07AA: 221 * GROUP OF DIODES TO BE LOGGED
07AA:20 45 06 222 BR25 JSR BR3 ;LOG AND SUBTRACT BACKGROUND DATA
07AD:CB 223 INY ;(2ND SET)
07AE:CC FE 07 224 CPY $07FE
07B1:90 F7 225 BCC BR25
07B3:AC FC 07 226 LDY $07FC ;LOAD WITH # OF DIODES TO BE IGNORED
07B6:20 20 06 227 BR26 JSR BR1 ;COUNT UNWANTED DIODES
07B9:88 228 DEY
07BA:D0 FA 229 BNE BR26
07BC:AC FE 07 230 LDY $07FE
07BF: 231 *
07BF:20 45 06 232 BR27 JSR BR3 ;START COUNTER FOR 3RD GROUP OF
07C2:CB 233 INY ;DIODES TO BE LOGGED
07C3:CC FD 07 234 CPY $07FD ;LOG AND SUBTRACT BACKGROUND DATA
07C6:90 F7 235 BCC BR27 ;3RD SET
07C8:AC FE 07 236 LDY $07FE ;DONE ?
07CB: 237 * ;IF NOT LOG AGAIN
;LOAD COUNTER WITH 4TH GROUP OF
;DIODES TO BE IGNORED
;COUNT UNWANTED DIODES

```

07CE:88	239	DEY		
07CF:D0 FA	240	BNE	BR28	
07D1:AC FD 07	241	LDY	\$07FD	;START COUNTER HERE FOR 4TH SET OF
07D4:	242 *			LOGGED DIODES
07D4:20 45 06	243 BR29	JSR	BR3	;LOG AND SUBTRACT SET #4
07D7:CB	244	INY		
07D8:CC FF 07	245	CPY	\$07FF	
07DB:90 F7	246	BCC	BR29	
07DD:EA	247	NOP		
07DE:EA	248	NOP		
07DF:EA	249	NOP		
07E0:EA	250	NOP		
07E1:EA	251	NOP		
07E2:EA	252	NOP		
07E3:20 67 06	253	JSR	BR5	;CHANGE ADDRESSES OF THE DATA STORAGE
07E6:	254 *			REGISTERS FOR THE NEXT SET OF DATA
07E6:F0	255	BEQ	FINISH	;IF DONE GO BACK TO BASIC
07E8:4C	256	JMP	BR19	;IF NOT DONE LOOK FOR ANOTHER
07EB:	257 *			START PULSE
07EB:6	258 FINISH	RTS		

APPENDIX 5

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APPENDIX 5

SCRATCHPAD MEMORY USAGE WITH THE APPLE II+

ADDRESS

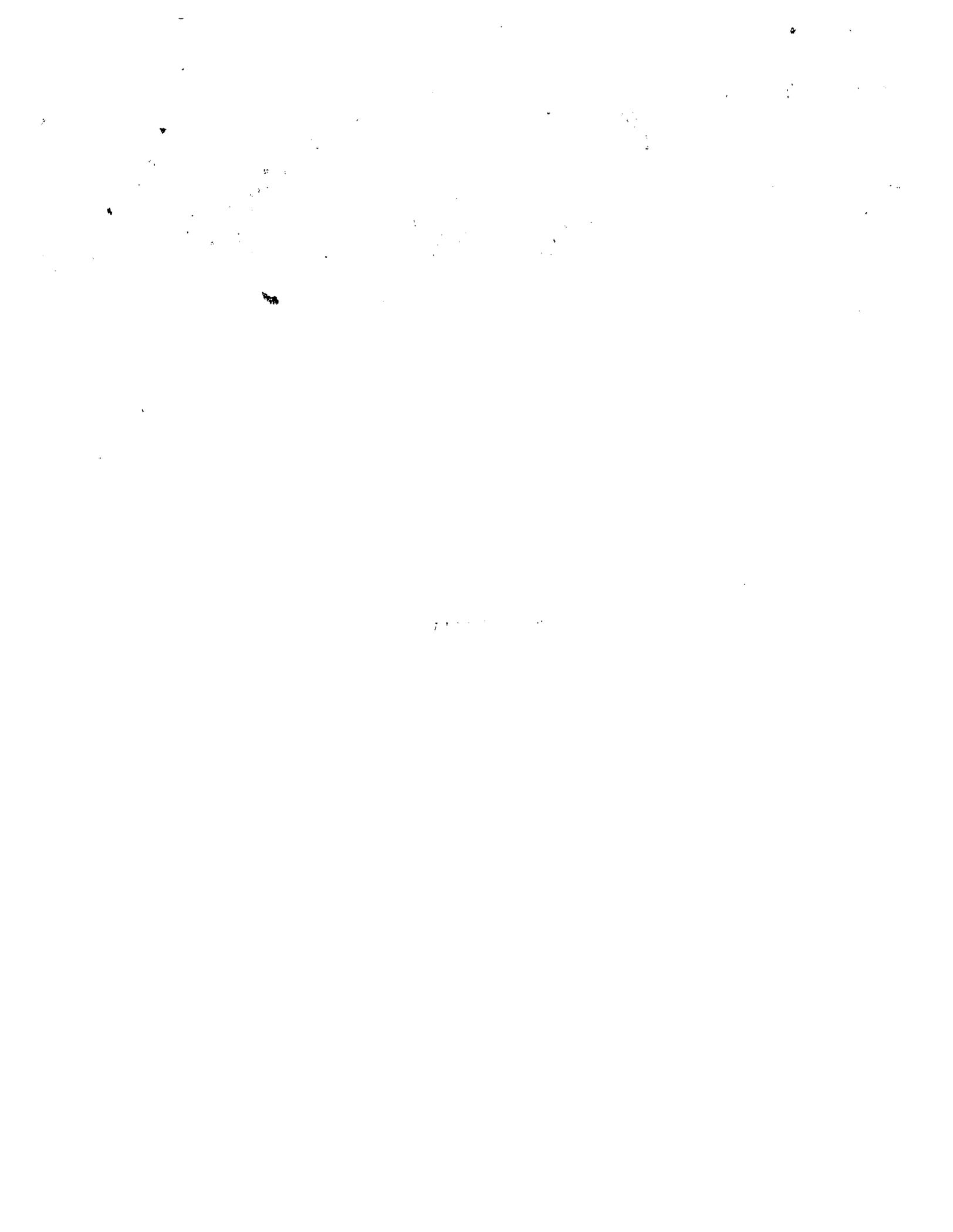
HEXADECIMAL	DECIMAL	USAGE BY THE INPUT BUFFER
7F01	32,513	8253 #3 COUNTER #0 LOW BYTE
7F02		8253 #3 COUNTER #0 HIGH BYTE
7F03		8253 #3 COUNTER #1 LOW BYTE
7404		8253 #3 COUNTER #1 HIGH BYTE
7F05		8253 #3 COUNTER #2 LOW BYTE
7F06		8253 #3 COUNTER #2 HIGH BYTE
7F07		8353 #4 COUNTER #0 LOW BYTE
7F08		8253 #4 COUNTER #0 HIGH BYTE
7F09		8253 #4 COUNTER #1 LOW BYTE
7F0A		8253 #4 COUNTER #1 HIGH BYTE
7F0B		8253 #4 COUNTER #2 LOW BYTE
7F0C		8253 #4 COUNTER #2 HIGH BYTE
7F0D	32,525	GAIN CODE ARRAY #0
7F0E		GAIN CODE ARRAY #1
7F0F		GAIN CODE ARRAY #2
7F10		GAIN CODE ARRAY #3
7F11		GAIN CODE ARRAY #4
7F12		GAIN CODE ARRAY #5
7F13	32,531	# OF REPLICATES ARRAY #0
7F14		# OF REPLICATES ARRAY #1
7F15		# OF REPLICATES ARRAY #2
7F16		# OF REPLICATES ARRAY #3
7F17		# OF REPLICATES ARRAY #4
7F18		# OF REPLICATES ARRAY #5
7F19	32,537	
7F1A		
7F1B		# OF REPLICATES, DUPLICATE
7F1C		LIST, TO BE DECREMENTED
7F1D		
7F1E		
7F1F	32,543	TEMPORARY ADDRESS ARRAY
		IDENTITY CODE
7F20		
7F21		
7F22		
7F23		
	32,549	GAIN AND CHANNEL CODE FOR SELECTED
		ARRAY

ADDRESS

HEXADECIMAL	DECIMAL	USAGE
7F25		USAGE BY BACKGROUND RAW DATA FILE
7F26	32,550	
7F27		
7F28		
7F29		
7F2A		
7F2B		8253 DATA SPECIFYING INTEGRATION
7F2C		TIME FOR THE BACKGROUND RAW DATA
7F2D		FILE
7F2E		
7F2F		
7F30		
7F31		
7F32	33,555	
7F33		
7F34		GAIN CODES FOR BACKGROUND
7F35		RAW DATA FILE
7F36		
7F37		
7F38	33,560	
7F39		
7F3A		# OF REPLICATES FOR BACKGROUND
7F3B		RAW DATA FILE
7F3C		
7F3D		
7F3E		
7F3F		
7F40		
7F41		
7F42		
7F43		8253 DATA SPECIFYING INTEGRATION
7F44		TIME FOR THE BACKGROUND RAW DATA
7F45		FILE
7F46		
7F47		
7F48		
7F49		
7F4A		
7F4B		
7F4C		
7F4D		
7F4E		
7F4F		
7F50	33,565	
7F51		

ADDRESS

HEXADECIMAL	DECIMAL	
7F52		# OF REPLICATES FOR ANALYTE MEANS
7F53		FILE
7F54		
7F55		
7F56	32,598	USAGE BY BACKGROUND MEANS FILE
7F47		
7F58		
7F59		
7F5A		
7F5B		8253 DATA SPECIFYING INTEGRATION
7F5C		TIMES FOR THE BACKGROUND MEANS
7F5D		FILE
7F5E		
7F5F		
7F60		
7F61		
7F62	32,610	
7F63		
7F64		GAIN CODES FOR BACKGROUND MEANS
7F65		FILE
7F66		
7F67		
7F68	32,616	
7F69		
7F6A		# OF REPLICATES FOR BACKGROUND
7F6B		MEANS FILE
7F6C		
7F6D		
7F6E	32,622	ADDRESS LOW BYTE } LOW BYTE ADDRESS
7F6F	32,623	ADDRESS HIGH BYTE } FOR DAC DISPLAYS
7F70	32,624	ADDRESS LOW BYTE } HIGH BYTE ADDRESS
7F71	32,625	ADDRESS HIGH BYTE } FOR DAC DISPLAYS
7F72	32,626	INNER LOOP CMP ADDRESS FOR RECORDER
7F73	32,627	DELAY VALUE FOR CHART RECORDER
		VALUE FOR RECORDER OUTPUT



## APPENDIX 6

### APPLE II+ PROGRAMS

The 6 array system programs are menu driven and user friendly. DRA is the display program that runs when the system is booted and its main purpose is to make sure that the disks are in their correct drives.

DRS is the main menu program.

SEL1 receives integration time information and stores it in scratchpad memory. It corrects the values of the integration times so that they follow the rules that avoid readout clashes. It then calls its own machine code program, MCLPA.ORBIO.

The machine code program closes the gates on the counters on the first two 8253 chips by generating a low logic level through the game I/O port. It checks again, this time in machine code, that the integration times follow the readout clash avoidance rules. It loads all the counters and then opens the gates so that the timing relations can be correct. The program then calls the next

## JLIST

```

5  REM PROGRAM**DRA**
10 HIMEM: 29439
20 REM INITIAL DISPLAY WHEN SYSTEM BOOTED
30 HOME
40 HTAB 8: PRINT "DIRECT READER DATA HANDLING"
50 HTAB 16: PRINT "PROGRAMS"
60 PRINT : PRINT "THE SYSTEM DISC SHOULD BE IN DRIVE #1": PRINT : PRINT
70 PRINT "FILE DISCS SHOULD BE IN DRIVE #2"
80 PRINT : FOR X = 1 TO 2000: NEXT X: PRINT
90 PRINT "*****"
100 PRINT : PRINT "DATA IS COLLECTED AND MANIPULATED IN": PRINT : PRINT
110 PRINT "BINARY AND CONVERTED TO VOLTAGE"
120 FOR X = 1 TO 4000: NEXT X: PRINT : PRINT
130 PRINT "SELECT ONE OF THE FOLLOWING OPTIONS BY"
140 PRINT "ENTERING THE NUMBER": PRINT : PRINT
150 PRINT CHR# (4);"RUNDRS"

```

```

5. REM PROGRAM **DRS**
10 HIMEM: 29439
15 REM PROGRAM FOR SELECTION OF OPTIONS
20 HTAB 4: PRINT "1. DEFINE THE INTEGRATION TIMES"
30 HTAB 4: PRINT "2. ACQUIRE SETS OF DATA POINTS"
40 HTAB 4: PRINT "3. SET UP A SHORT INTEGRATION TIME"
50 HTAB 9: PRINT "FOR A SINGLE ARRAY"
60 HTAB 4: PRINT "4. SUBTRACT BACKGROUND AND"
70 HTAB 9: PRINT "STORE AS MEANS"
80 HTAB 4: PRINT "5. DISPLAY GRAPHICALLY ON THIS SCREEN"
90 HTAB 4: PRINT "6. SAVE DATA ON DISKETTE"
100 HTAB 4: PRINT "7. DISPLAY ON AN OSCILLOSCOPE"
110 HTAB 4: PRINT "8. OUTPUT TO CHART RECORDER"
120 HTAB 4: PRINT "9. DISPLAY VALUES ON THIS SCREEN"
130 HTAB 4: PRINT "10. SMOOTH (PAIR AVERAGE) THE"
140 HTAB 9: PRINT "INPUT BUFFER"
150 HTAB 4: PRINT "11. OBTAIN DATA VALUES FROM A FILE"
160 HTAB 4: PRINT "12. CALCULATE CONCENTRATIONS"
170 PRINT "ENTER INSTRUCTION # AND PRESS RETURN"
180 INPUT B$
185 D$ = CHR# (17) + CHR# (4)
190 ON VAL (B$) GOTO 210, 220
200 IF VAL (B$) > 12
210 PRINT D$;"RUNSEL1"
220 PRINT D$;"RUNSEL2"
230 PRINT D$;"RUNSEL3"
240 PRINT D$;"RUNSEL4"
250 PRINT D$;"RUNSEL5"
260 PRINT D$;"RUNSEL6"
270 PRINT D$;"RUNSEL7"
280 PRINT D$;"RUNSEL8"
290 PRINT D$;"RUNSEL9"
300 PRINT D$;"RUNSEL10"
310 PRINT D$;"RUNSEL11"

```

```

5  REM PROGRAM **SEL1**
10  HIMEM: 29439
15  REM PROGRAM TO SET THE INTEGRATION TIMES FOR SIX ARRAYS
20  HOME
30  PRINT "IF NEW INTEGRATION TIMES ENTER 1"
40  PRINT
50  PRINT "IF SAME AS BEFORE ENTER 2"
60  INPUT P$
70  ON VAL (P$) GOTO 90,310
90  PRINT
100 PRINT "ENTER INTEGRATION TIMES IN SECONDS FOR SIX ARRAYS(MAXIMUM 205 SECS)
110 PRINT "IF ARRAY NOT USED ENTER 0"
120 FOR I = 0 TO 5:
125  REM FOR EACH ARRAY
130  PRINT "ARRAY # ";I: INPUT B
140  E = 0.5:F = 256:D = 3.1289E - 3:H = 32
150  IF B = 0 THEN 230
155  REM ROUND OFF INTEGRATION TIME TO AN INTEGER MULTIPLE
156  REM OF THE STANDARD TIME INCREMENT
160  C = INT (B / (D * H) + E) * H
165  REM DIVIDE INTO A TWO BYTE VALUE AND POKE INTO SCRATCH PAD MEMORY
170  T = C / F:G = INT (T)
180  J = INT (F * (T - G) + E)
190  IF G > 255 THEN PRINT "TOO LONG": GOTO 130
200  IF G > 0 THEN 240
210  IF J < 32 THEN PRINT "TOO SHORT": GOTO 320
220  GOTO 240
230  G = 0:J = H:C = H
240  POKE 32513 + 2 * I,J: POKE 32514 + 2 * I,G
250  L = C * D
260  L = INT (L * 10 ^ 4 + .5) / INT (10 ^ 4 + .5)
270  PRINT CHR$(4);"PR#1"
280  PRINT "ACTUAL INTEGRATION TIME ARRAY# ";I:"=";L:"SECONDS"
290  PRINT CHR$(4);"PR#0"
300  NEXT I
305  REM RUN THE MACHINE CODE PROGRAM THAT LOADS THE 8253 COUNTERS
310  PRINT CHR$(4);"BRUNMC1BA.OBJ0"
315  REM NOW COLLECT DATA
320  PRINT CHR$(4);"RUNSEL2"

```

SOURCE FILE: MC1BA

```

0000:      1 *****MC1BA*****
0000:      2 *PART OF PROGRAM FOR SETTING INTEGRATION TIMES FOR 6 ARRAYS
0000:      3 *THE BASIC PROGRAM HAS PREVIOUSLY POKED THE INTEGRATION TIMES
      INTO SCRATCH PAD MEMORY
----- NEXT OBJECT FILE NAME IS MC1BA.OBJO
9237:      4      ORG  $9237
9237:      5 *CLOSE THE GATE ON 8253 #1 COUNTER 0 DURING LOADING
9237:AD 58 C0      6      LDA  $C058
C000:      7 CLK  EQU  $C000
923A:      8 *FOR 8253 # 1
923A:A9 34      9      LDA  ##34      ;LOAD MODE WORD COUNTER 0 MODE 2
923C:BD D3 C0    10     STA  CLK+3      ;LOAD INTO 8253 #1
923F:A9 50      11     LDA  ##50      ;LOAD MODE WORD COUNTER 1 MODE 0
9241:BD D3 C0    12     STA  CLK+3      ;LOAD INTO 8253 #1
9244:A9 90      13     LDA  ##90      ;LOAD MODE WORD COUNTER " MODE 2
9246:BD D3 C0    14     STA  CLK+3      ;LOAD INTO 8253 #1
9249:      15 *COUNTER #0 IN MODE 2 DIVIDES CLOCK RATE BY 3200
9249:A9 80      16     LDA  ##80      ;LOAD COUNTER 0 LOW BYTE
924B:BD D0 C0    17     STA  CLK      ;WRITE LOW BYTE
924E:A9 0C      18     LDA  ##0C      ;LOAD COUNTER 0 HIGH BYTE
9250:BD D0 C0    19     STA  CLK      ;WRITE HIGH BYTE
9253:      20 *COUNTERS #1 AND 2 OF 8253 #1 AND ALL 3 COUNTERS OF 8253 #2
9253:      21 *ARE IN MODE 0.THEY GATE COUNTERS #1 AND 2 OF 8253 #3 AND
9253:      22 *ALL 3 COUNTERS OF 8253 #4 THEREBY DELAYING THE START OF
9253:      23 *THEIR COUNTS
9253:A9 04      24     LDA  ##04      ;LOAD COUNTER 1 LOW BYTE (ONLY)
9255:BD D1 C0    25     STA  CLK+1      ;WRITE LOW BYTE (ONLY)
9258:A9 09      26     LDA  ##09      ;LOAD COUNTER 2 LOW BYTE (ONLY)
925A:BD D2 C0    27     STA  CLK+2      ;WRITE LOW BYTE (ONLY)
925D:      28 *FOR 8253 # 2
925D:A9 10      29     LDA  ##10      ;LOAD MODE WORD COUNTER 0 MODE 0
925F:BD D7 C0    30     STA  CLK+7      ;LOAD INTO 8253 #2
9262:A9 50      31     LDA  ##50      ;LOAD MODE WORD COUNTER 1 MODE 0.
9264:BD D7 C0    32     STA  CLK+7      ;LOAD INTO 8253 #2
9267:A9 90      33     LDA  ##90      ;LOAD MODE WORD COUNTER 2 MODE 0
9269:BD D7 C0    34     STA  CLK+7      ;LOAD INTO 8253 #2
926C:A9 0F      35     LDA  ##0F      ;LOAD COUNTER 0 LOW BYTE (ONLY)
926E:BD D4 C0    36     STA  CLK+4      ;WRITE LOW BYTE (ONLY)
9271:A9 14      37     LDA  ##14      ;LOAD COUNTER 1 LOW BYTE (ONLY)
9273:BD D5 C0    38     STA  CLK+5      ;WRITE LOW BYTE (ONLY)
9276:A9 19      39     LDA  ##19      ;LOAD COUNTER 2 LOW BYTE (ONLY)
9278:BD D6 C0    40     STA  CLK+6      ;WRITE LOW BYTE (ONLY)
927B:      41 *8253'S #3 AND 4 CONTROL THE ACTUAL INTEGRATION TIMES.
927B:      42 *AFTER MODE WORDS ARE LOADED (ALL COUNTERS IN MODE 2)
927B:      43 *THE COUNTERS ARE LOADED WITH THEIR COUNTS FROM SCRATCH
927B:      44 *PAD MEMORY.WHERE THEY WERE PLACED BY THE BASIC PROGRAM
927B:A9 34      45     LDA  ##34      ;LOAD MODE WORD COUNTER 0 MODE 2
927D:BD DB C0    46     STA  CLK+8      ;LOAD INTO 8253 #3
9280:A9 74      47     LDA  ##74      ;LOAD MODE WORD COUNTER 1 MODE 2
9282:BD DB C0    48     STA  CLK+8      ;LOAD INTO 8253 #3
9285:A9 B4      49     LDA  ##B4      ;LOAD MODE WORD COUNTER 2 MODE 2
9287:BD DB C0    50     STA  CLK+8      ;LOAD INTO 8253 #3
928A:AD 01 7F    51     LDA  $7F01      ;FETCH LOW BYTE 1ST INTEGRATION TIME
928D:29 E0      52     AND  ##E0      ;MAKE SURE IT IS A MULTIPLE OF 32
928F:BD DB C0    53     STA  CLK+8      ;WRITE LOW BYTE
9292:AD 02 7F    54     LDA  $7F02      ;FETCH HIGH BYTE 1ST INTEGRATION TIME
9295:BD DB C0    55     STA  CLK+8      ;WRITE HIGH BYTE
9298:AD 03 7F    56     LDA  $7F03      ;FETCH LOW BYTE 2ND INTEGRATION TIME
929B:29 E0      57     AND  ##E0      ;GUARANTEE THAT IT IS A MULTIPLE OF 32
929D:BD DB C0    58     STA  CLK+8      ;WRITE LOW BYTE

```

92A0:AD 04 7F	59	LDA \$7F04	;FETCH HIGH BYTE 2ND INTEGRATION TIME
92A3:BD 09 C0	60	STA CLK+9	;WRITE HIGH BYTE
92A6:AD 05 7F	61	LDA \$7F05	;FETCH LOW BYTE 3RD INTEGRATION TIME
92A9:29 E0	62	AND \$E0	;A MULTIPLE OF 32 ?
92AB:BD DA C0	63	STA CLK+\$A	;WRITE LOW BYTE
92AE:AD 06 7F	64	LDA \$7F06	;FETCH HIGH BYTE 3RD INTEGRATION TIME
92B1:BD DA C0	65	STA CLK+\$A	;WRITE HIGH BYTE
92B4:A9 34	66	LDA \$B4	;LOAD MODE WORD COUNTER 0 MODE 2
92B6:BD DF C0	67	STA CLK+\$F	;LOAD INTO 8253 #4
92B9:A9 74	68	LDA \$74	;LOAD MODE WORD COUNTER 0 MODE2
92BB:BD DF C0	69	STA CLK+\$F	;LOAD INTO 8253 #4
92BE:A9 B4	70	LDA \$B4	;LOAD MODE WORD COUNTER 0 MODE 2
92C0:BD DF C0	71	STA CLK+\$F	;LOAD INTO 8253 #4
92C3:AD 07 7F	72	LDA \$7F07	;FETCH LOW BYTE 4TH INTEGRATION TIME
92C6:29 E0	73	AND \$E0	;A MULTIPLE OF 32 ?
92C8:BD DC C0	74	STA CLK+\$C	;WRITE LOW BYTE
92CB:AD 08 7F	75	LDA \$7F08	;FETCH HIGH BYTE 4TH INTEGRATION TIME
92CE:BD DC C0	76	STA CLK+\$C	;WRITE HIGH BYTE
92D1:AD 09 7F	77	LDA \$7F09	;FETCH LOW BYTE 5TH INTEGRATION TIME
92D4:29 E0	78	AND \$E0	;A MULTIPLE OF 32 ?
92D6:BD DD C0	79	STA CLK+\$D	;WRITE LOW BYTE
92D9:AD 0A 7F	80	LDA \$7F0A	;FETCH HIGH BYTE 5TH INTEGRATION TIME
92DC:BD DD C0	81	STA CLK+\$D	;WRITE HIGH BYTE
92DF:AD 0B 7F	82	LDA \$7F0B	;FETCH LOW BYTE 6TH INTEGRATION TIME
92E2:29 E0	83	AND \$E0	;A MULTIPLE OF 32 ?
92E4:BD DE C0	84	STA CLK+\$E	;WRITE LOW BYTE
92E7:AD 0C 7F	85	LDA \$7F0C	;FETCH HIGH BYTE 6TH INTEGRATION TIME
92EA:BD DE C0	86	STA CLK+\$E	;WRITE HIGH BYTE
92ED:EA	87	NOP	
92EE:EA	88	NOP	
92EF:EA	89	NOP	
92F0:	90	*ALL COUNTERS LOADED SO OPEN THE GATE ON 8253 #1 COUNTER 0	
92F0:AD 50 C0	91	LDA \$C059	
92F3:40	92	RTS	;GO AND DO SOMETHING ELSE

The program SEL2 is the data acquisition program. It has provisions for signal averaging but not background subtraction which is handled separately. The BASIC program asks for, and POKES into scratchpad memory, the range setting for the programmable A113 analog to digital converter and the number of replications required for each array. It then calls the machine code program MC2AA.OBJ0 to get the data values and later calls other programs to transfer the data to other memory locations (files) before or after calculation of mean values.

The machine language program MC2AA is relatively complex. It first makes a second copy of the replications requested, the second set to be decremented as counters. It looks for the rising edge of a start pulse and identifies the array about to be read out. It then checks if the array data set is needed and if it is, it selects the gain code for that array from scratch pad memory and sets the A/DC to the required range and channel. The program then generates the base addresses for the low, high and carry bytes of data for that array, (indexing is used to differentiate between the diodes) and writes them forward in the program. It then looks for the falling edge of the start pulse and commences the data acquisition loop for that array. It cues the A/DC to convert on receipt of a trigger and polls for a conversion completed signal. The A/DC output values are read and stored in the appropriate addresses.

After each array has been logged, the replicate count for that array is decremented. When all replicate counts have been decremented to zero the program ends.

Other programs called by SEL2 are:-

- i. MC2B.OBJ0 which transfers the new data to the Background Raw Data File using machine code.
- ii. SEL2A which calculates the mean values and stores them in the Analyte Means File; MC5 is used to transfer the replication and gain parameters in machine code.
- iii. SEL2B and MC6 which perform the same function, transferring to the Background Means File.

```

5  REM PROGRAM **SEL2**
10 HIMEM: 29439
15 REM THIS IS THE DATA ACQUISITION PROGRAM
20 HOME
30 HTAB 5: PRINT "ACQUISITION OF DATA POINTS": PRINT : PRINT
40 HTAB 5: PRINT "TWO PARAMETERS ARE REQUIRED"
50 PRINT : PRINT : PRINT ;"1. THE CONVERSION RANGE OF THE ADC": PRINT : PRINT
60 PRINT "2. THE NUMBER OF REPLICATES FOR EACH      ARRAY"
70 PRINT : PRINT : PRINT ;"IF NEW PARAMETERS ENTER 1": PRINT
75 PRINT "IF THE SAME ENTER 2 "
80 INPUT M
90 IF M = 1 THEN 110
100 IF M = 2 THEN 400
110 FOR I = 0 TO 5
120 D$ = CHR$ (4)
130 PRINT D$;"PR#1"
140 PRINT "ARRAY #";I
150 PRINT D$;"PR#0"
160 PRINT "SELECT THE # CORRESPONDING TO THE      EXPECTED SIGNAL RANGE"
165 REM SET THE A/DC RANGE
170 PRINT "0. 0 TO +5.0VOLTS"
180 PRINT "1  0 TO +1.0VOLTS"
190 PRINT "2  0 TO +0.5VOLTS"
200 PRINT "3  0 TO +0.1VOLTS"
210 PRINT "4 -5.0 TO +5.0VOLTS"
220 PRINT "5 -1.0 TO +1.0VOLTS"
230 PRINT "6 -0.5 TO +0.5VOLTS"
240 PRINT "7 -0.1 TO +0.1VOLTS"
250 INPUT K
260 PRINT D$;"PR#1"
270 PRINT "RANGE #";K
280 PRINT D$;"PR#0"
290 POKE 32525 + I,K * 16 + I
300 PRINT "SELECT THE # OF REPLICATES FOR THIS      ARRAY (MAXIMUM 127"
310 PRINT "IF ARRAY NOT USED ENTER 0"
320 INPUT L
330 PRINT D$;"PR#1"
340 PRINT "# OF REPLICATES=";L
350 PRINT D$;"PR#0"
360 POKE 32531 + I,L
370 PRINT
380 PRINT
390 NEXT I
395 REM WAIT FOR THE ARRAYS TO BE CLEARED
400 HOME : INVERSE : VTAB 3: PRINT "WHEN THE SOURCE IS READY"
410 VTAB 6: PRINT "PRESS THE WHITE BUTTON ON THE GREY BOX"
420 VTAB 9: PRINT "WAIT UNTIL THE GREEN LIGHT COMES ON"
430 VTAB 12: PRINT "THEN PRESS ANY KEY TO COLLECT DATA"
440 NORMAL
450 CALL - 756
455 PRINT "HERE WE GO"
460 REM RUN THE MACHINE CODE PROGRAM TO COLLECT DATA
470 PRINT CHR$ (4);"BRUNMC2AA.OBJ0"
480 HOME
490 PRINT "CHOOSE!-"
495 PRINT
500 HTAB 5: PRINT "1. RETURN TO MAIN MENU"

```

```
510 PRINT
520 HTAB 7: PRINT "2. TRANSFER RAW DATA TO"
530 HTAB 10: PRINT "BACKGROUND STORAGE"
540 PRINT
550 HTAB 7: PRINT "3. CALCULATE MEANS FOR "
560 HTAB 10: PRINT "ANALYTE DATA"
570 PRINT
580 HTAB 7: PRINT "4. CALCULATE MEANS FOR "
590 HTAB 10: PRINT "BACKGROUND DATA"
595 PRINT
600 INPUT "ENTER 1,2,3 OR 4 ";E$
605 D$ = CHR$(4)
610 ON VAL (E$) GOTO 620,640,650,660
620 PRINT D$;"RUNDRS"
640 PRINT D$;"BRUNMC2B.DBJ0"
645 GOTO 620
650 PRINT D$;"RUNSEL2A"
655 GOTO 620
660 PRINT D$;"RUNSEL2B"
670 GOTO 620
```

SOURCE FILE: MC2AA

----- NEXT OBJECT FILE NAME IS MC2AA.OBJO

```

9200:          1          ORG    $9200
9200:          2 *PROGRAM TO READ ALL 6 ARRAYS AND RECORD DIGITISED VALUES
C400:          3 PORT   EQU    $C400
C0B0:          4 ADC     EQU    $C0B0
9200:DB       5          CLD
9201:7B      6          SEI
9202:          7 *COPY THE REPLICATION REQUIRED, 2ND SET TO BE DECREMENTED
9202:A2 05    8          LDX    $005
9204:BD 13 7F 9 BR1     LDA    $7F13,X
9207:9D 19 7F 10        STA    $7F19,X
920A:CA       11        DEX
920B:10 F7    12        BPL    BR1
920D:EA       13        NOP
920E:EA       14        NOP
920F:EA       15        NOP
9210:          16 *SIGNAL AVERAGING REQUIRES USE OF ADDITION.
9210:          17 *STORAGE MEMORY MUST BE ZERO FILLED BEFORE DATA
9210:A9 01    18        LDA    $001
9212:8D 1B C4 19        STA    PORT+$1B ;SET DDRA FOR INPUTS ON PCA
9215:A2 00    20        LDX    $000
9217:A9 00    21        LDA    $000
9219:9D 00 80 22 BR7    STA    $8000,X
921C:9D 00 81 23        STA    $8100,X
921F:9D 00 82 24        STA    $8200,X
9222:9D 00 83 25        STA    $8300,X
9225:9D 00 84 26        STA    $8400,X
9228:9D 00 85 27        STA    $8500,X
922E:9D 00 86 28        STA    $8600,X
922E:9D 00 87 29        STA    $8700,X
9231:9D 00 88 30        STA    $8800,X
9234:CA       31        DEX
9235:D0 E2    32        BNE    BR2
9237:A9 00    33 BR1     LDA    $000
9239:8D 13 C4 34        STA    PORT+$13 ;SET DDRA FOR INPUTS ON PCA
923C:          35 *LOOK FOR THE RISING EDGE OF THE START PULSE
923C:A9 01    36        LDA    $001
923E:8D 1C C4 37        STA    PORT+$1C ;SET PCR FOR RESPONSE ON CA1
9241:AD 11 C4 38        LDA    PORT+$11 ;BUT FIRST CLEAR THE IFR
9244:AD 1D C4 39 BR2    LDA    PORT+$1D ;READ IFR
9247:29 02    40        AND    $02 ;CHECK FOR CA1 INTERRUPT FLAG
9249:F0 F9    41        BEQ    BR3 ;IF NOT FOUND KEEP LOOKING
924E:          42 *RELEASE TRIP LEAD ARRAY IDENTIFY CODE FROM THE 7414B CHIP
924E:AD 11 C4 43        LDA    PORT+$11
924E:29 07    44        AND    $07 ;CLEAR UPPER 5 BITS
9250:8D 1F 7F 45        STA    $7F1F ;STORE IT
9253:AA       46        TAX ;STORE ARRAY IDENTITY IN X REGISTER
9254:8D 19    47        LDA    $7F19,X ;LOAD THE REPLICATION COUNT
9257:F0 F9    48        BEQ    BR4
9259:          49 *IF DECREMENTED COUNTER IS ZERO REJECT THE START PULSE
9259:          50 *AND LOOK FOR ANOTHER ONE
9259:30 DC    51        BHI    BR4 ;A SAFETY TRAP IN CASE OF ACCIDENTS
925E:8D 0D 7F 52        LDA    $7F0D,X ;SELECT THE GAIN CODE FOR THE AREA
925E:8D 21 7F 53        STA    $7F21 ;AND STORE IT
9261:          54 *A DUMMY WRITE TO IS NOW MADE TO THE ADC TO GIVE THE CHAN
9261:          55 *SWITCHES A D AMPLIFIER TIME TO SETTLE, THE ADC IS
9261:          56 *TO BE USED TO TRIGGER THE FLAG WHEN DONE
9261:8D E7 C0 57        LDA    $E7C0
9261:          58

```

```

9267:          59 *THE CODE IS NOW SHIFTED ONE BIT RIGHT,IF IT IS ODD THE
9267:          60 *CARRY FLAG IS SET,IF EVEN THE CARRY FLAG IS RESET
9267:4A        61          LSR A
9268:          62 *SAVE THE UPPER BITS OF THE CODE IN THE X REGISTER
9268:AA        63          TAX
9269:          64 *THE LOW BYTE OF THE BASE ADDRESSES FOR DATA STORAGE ARE
9269:          65 *SELECTED ACCORDING TO THE STATE OF THE CARRY AND WRITEN
9269:          66 *FORWARDS IN THE PROGRAM
9269:80 16      67          BCS BR5
926E:          68 *IF THE ARRAY IS EVEN THE LOW BYTE BASE ADDRESS IS $00
926E:A9 00     69          LDA #$00
926D:8D D3 92  70          STA ADD1+1
9270:8D D6 92  71          STA ADD2+1
9273:8D DE 92  72          STA ADD3+1
9276:8D E1 92  73          STA ADD4+1
9279:8D E4 92  74          STA ADD5+1
927C:8D E9 92  75          STA ADD6+1
927F:F0 14     76          BEQ BR6
9281:          77 *IF THE ARRAY IS ODD THE LOW BYTE BASE ADDRESS IS $80
9281:A9 80     78          LDA #$80
9283:8D D3 92  79          STA ADD1+1
9286:8D D6 92  80          STA ADD2+1
9289:8D DE 92  81          STA ADD3+1
928C:8D E1 92  82          STA ADD4+1
928F:8D E4 92  83          STA ADD5+1
9292:8D E9 92  84          STA ADD6+1
9295:          85 *RELOAD WITH THE UPPER BITS OF THE ARRAY CODE AND ADD THEM TO
9295:          86 *THE STARTING ADDRESSES IN TURN TO GET THE HIGH BYTE BASE
9295:          87 *ADDRESSES FOR THE LOW,HIGH AND CARRY FILES FOR DATA
9295:          88 *STOREAGE AND WRITE THEM FORWARDS IN THE PROGRAM
9295:8A          89          TXA
9296:18          90          CLC          ;CLEAR CARRY FLAG IF SET
9297:69 80     91          ADC #$80
9299:8D D4 92  92          STA ADD1+2
929C:8D D7 92  93          STA ADD2+2
929F:8A          94          TXA
92A0:69 83     95          ADC #$83
92A2:8D DF 92  96          STA ADD3+2
92A5:8D E2 92  97          STA ADD4+2
92AB:8A          98          TXA
92A9:69 86     99          ADC #$86
92AE:8D E5 92 100         STA ADD5+2
92AE:8D EA 92 101         STA ADD6+2
92B1:          102 *LOAD FOR THE FALLING EDGE OF THE START PULSE
92B1:A9 00     103         LDA #$00
92B3:8D 1C C4 104         STA PORT+$1C ;SET PCR FOR FALLING EDGES
92B6:AD 11 C4 105         LDA PORT+$11 ;CLEAR THE IFR
92B9:AD 10 C4 106         LDA PORT+$10 ;READ IFR
92BC:29 02     107         AND #$02 ;CHECK FOR CA1 INTERRUPT FLAG
92BE:F0 F9     108         FEQ BR7 ;IF NOT FOUND KEEP LOOKING
92C0:A2 7F     109         LDY #$7F ;TO LOG 128 DIODES
92C2:AD 24 7F 110         LDA $7F24 ;LOAD WITH THE GAIN CODE
92C5:8D E3 C0 111         STA ADC+9 ;INITIATE CONVERSION AFTER TRIGGER
92C8:AD E1 C0 112         LDA ADC+$1 ;LOOK FOR CONVERSION COMPLETED FLAG
92CE:29 80     113         AND #$80 ;1 IN MSE IS DONE FLAG
92CD:F0 F9     114         BEQ BR8 ;IF NOT DONE KEEP LOOKING
92CF:AD E0 C0 115         LDA ADC ;FETCH LOW BYTE OF CONVERSION
92D2:7D FF FF 116        ADD1  ADC $FFFF,X ;ADD IT TO DATA
92D4:8D FF FF 117        STA $FFFF,Y ;ALREADY COLLECTED
92D5:8D FF FF 118        LDA ADC+1 ;FETCH HIGH BYTE OF CONVERSION

```

```

92DB:29 0F 119 AND $0F ;CLEAR OFF UPPER 4 BITS
92DD:7D FF FF 120 ADD3 ADC $FFFF,X ;ADD IT TO DATA
92E0:9D FF FF 121 ADD4 STA $FFFF,X ;ALREADY COLLECTED
92E3:BD FF FF 122 ADD5 LDA $FFFF,X ;LOAD THE CARRY BYTE
92E6:69 00 123 ADC $00 ;ADD THE CARRY FLAG IF SET
92E8:9D FF FF 124 ADD6 STA $FFFF,X ;UPDATE THE FILE
92EB:CA 125 DEX
92EC:10 D4 126 BPL BR9 ;LOG ANOTHER DIODE IF NOT DONE
92EE: 127 *THE ARRAY HAS BEEN LOGGED. DECREMENT IT'S REPLICATE COUNT
92EE:AE 1F 7F 128 LDX $7F1F ;LOAD WITH THE ARRAY CODE
92F1:DE 19 7F 129 DEC $7F19,X ;DECREMENT THE CORRECT REPLICATE COUNT
92F4: 130 *NO TEST FOR COMPLETION OF ALL REQUESTED ARRAYS AND LOG
92F4:1B 131 CLC
92F5:AD 19 7F 132 LDA $7F19
92F8:6D 1A 7F 133 ADC $7F1A
92FB:6D 1B 7F 134 ADC $7F1B
92FE:6D 1C 7F 135 ADC $7F1C
9301:6D 1D 7F 136 ADC $7F1D
9304:6D 1E 7F 137 ADC $7F1E
9307:B0 02 138 BCS BR9
9309:F0 03 139 BEQ BRA
930B:4C 37 140 BRE JMF BR9 ;IF NONE IN ARRAY
930E:60 141 BRA BIF

```

SOURCE FILE: MC2E

----- NEXT OBJECT FILE NAME IS MC2E.OBJ

```

9200: 1 ORG $9200
9200: 2 *INCLUDE 'RAW DATA.FRM'
9200: 3 *SPACE .THIS IS
9200:1B 4 CLC
9201:A2 00 5 LDX $00
9203:BD 00 80 6 LDA $8000,X
9206:9D 00 89 7 STA $8900,X
9209:BD 00 81 8 LDA $8100,X
920C:9D 00 8A 9 STA $8A00,X
920F:BD 00 82 10 LDA $8200,X
9212:9D 00 8B 11 STA $8B00,X
9215:BD 00 83 12 LDA $8300,X
9218:9D 00 8C 13 STA $8C00,X
921E:BD 00 84 14 LDA $8400,X
921E:9D 00 8D 15 STA $8D00,X
9221:BD 00 85 16 LDA $8500,X
9224:9D 00 8E 17 STA $8E00,X
9227:BD 00 86 18 LDA $8600,X
922A:9D 00 8F 19 STA $8F00,X
922D:BD 00 87 20 LDA $8700,X
9230:9D 00 90 21 STA $9000,X
9233:BD 00 8F 22 LDA $8800,X
9236:9D 00 23 STA $9100,X
9239:CA 24 DEX
923A:DA 07 25 BNE BR1
923C: 26 *NSF THE
923C:A2 17 27 LDX $01
923E:BD 01 7F 28 LDA $7F
9241:9D 21 29 STA
9244:CA 30 DEX
9245:10 31 BRA

```

```

1  REM PROGRAM **SELZA**
5  HIMEM: 29439
10 REM THIS OPTION CALCULATES MEANS FROM DATA IN THE INPUT BUFFER
12 REM AND STORES THEM IN THE ANALYTE MEANS FILE
20 D$ = CHR$(4)
30 AA = 32768:B = 128:C = 768:D = 1536:E = 32531:F = 30976:G = 256
120 FOR I = 0 TO 5
125 W = F + I * B:X = W + C
130 A = AA + I * B:K = A + C:L = A + D:M = PEEK (E + I)
135 IF M = 0 THEN 200
140 FOR N = 0 TO 127
150 O = PEEK (A + N):P = PEEK (K + N):Q = PEEK (L + N)
160 R = ((Q * S + P) * S + O) / INT (R / S)
170 U = INT (R - S * T)
180 POKE W + N,U: POKE X + N,T
190 NEXT N
200 NEXT I
210 PRINT D$;"BRUNMC5 DE"

```

```

SOURCE FILE: M... FILE NAME IS MCS.OBJD
-----
9200:          1          ORG $9200
9200:          2 *TRANSFER REPLICATION AND DATA DATA
9200:          3 *FOR ANALYTIC MEANS FILE
9200:          4 *FOR THE INPUT BUFFER
9200:A2 17     5          LDX #17
9202:BD 01     6          LDA $7F01
9205:9D       7          STA #...
920E:CA       8          DEX
9210:         9          ...

```

```

1  REM PROGRAM**SELZB**
5  HIMEM: 29439
10 REM THIS OPTION CALCULATES MEANS FROM DATA IN THE INPUT BUFFER
12 REM AND STORES THEM IN THE BACKGROUND MEANS FILE
20 D$ = CHR$(4)
30 AA = 32768:B = 128:C = 768:D = 1536:E = 32531:F = 29440:G = 256
120 FOR I = 0 TO 5
125 W = F + I * B:X = W + C
130 A = AA + I * B:K = A + C:L = A + D:M = PEEK (E + I)
135 IF M = 0 THEN 200
140 FOR N = 0 TO 127
150 O = PEEK (A + N):P = PEEK (K + N):Q = PEEK (L + N)
160 R = ((O * S + P) * S + D) / M:T = INT (R / S)
170 U = INT (R - S * T)
180 POKE W + N,U: POKE X + N,T
190 NEXT N
200 NEXT I
210 PRINT D$;"BRUNMC6.OBJ"
220 FOR I = 0 TO 5

```

SOURCE FILE: MC6

----- NEXT OBJECT FILE NAME IS MC6.OBJ0

9200:	1	ORG	9200
9200:	2	*TRANSFER REPLICATION AND GATH DATA	
9200:	3	*FOR BACKGROUND MEANS FILE	
9200:	4	*FROM THE INPUT BUFFER	
9200:A2 17	5	LDX	##17
9202:BD 01 7F	6	LDI	7F01,X
9205:9D 56 7F	7	STA	7F56,X
9208:CA	8	DEX	
9209:10	9	BPL	BP1
920A:10	10	RTI	

SEL3 is similar to SEL1 except that it runs one array for a short integration time (down to 0.018 s) while the other 5 arrays stay at 205 s integration.

MC10.OBJ0 loads zero as default values in the integration time scratch pad addresses. The BASIC program then corrects the scratch pad addresses for the array of interest.

MC10B.OBJ0 is similar to MC1BA.OBJ0 except that it does not check for obedience of the readout clash prevention rules.

```

10 REM PROGRAM **SEL3**
20 HIMEM: 29439
30 HOME
40 PRINT "THIS OPTION RUNS A SINGLE ARRAY"
50 PRINT
60 PRINT "WITH A SHORT INTEGRATION TIME"
70 PRINT
80 PRINT "THE OTHER 5 ARRAYS ARE LEFT WITH"
90 PRINT
100 PRINT "A 205 SECOND INTEGRATION TIME"
110 PRINT
120 PRINT "THE SELECTED ARRAY CAN BE READ"
130 PRINT
140 PRINT "OUT AFTER A MINIMUM OF 0.018"
150 PRINT
160 PRINT "SECONDS"
170 PRINT
180 FOR X = 0 TO 5000: NEXT X
190 PRINT "THIS SERVES 2 PURPOSES: "
200 PRINT
210 HTAB 4: PRINT "1. GIVES A HIGH REFRESHMENT"
220 PRINT
230 HTAB 7: PRINT "RATE FOR AN OSCILLOSCOPE"
240 PRINT
250 HTAB 7: PRINT "DURING ARRAY SET UP"
260 PRINT
270 HTAB 4: PRINT "2. ALLOWS DATA COLLECTION"
280 PRINT
290 HTAB 7: PRINT "FOR A VERY STRONG SIGNAL"
300 REM FORCE DFFAULT INTEGRATION TIMES OF 205 SECONDS INTO SCRATCH PAD MEMORY
310 PRINT CHR*(4);"BRUNMC10.0EJ0"
320 PRINT
330 PRINT
340 PRINT
350 HTAB 4: PRINT "ENTER ARRAY # FOR SHORT"
360 PRINT
370 HTAB 4: PRINT "INTEGRATION TIME ": INPUT I
380 PRINT
390 PRINT
400 HTAB 4: PRINT "ENTER IT'S INTEGRATION TIME"
410 PRINT
420 HTAB 4: PRINT "IN SECONDS. ": INPUT B
430 E = 0.5:F = 256:D = 3.1281E - 3:H = 32
440 C = INT (B / D + E)
450 T = C / F:G = INT (T)
460 J = INT (F * (T - G) + E)
470 IF G > 255 THEN PRINT "TOO LONG": GOTO 400
480 IF G > 0 THEN 510
490 IF J < .6 THEN PRINT "TOO SHORT": GOTO 400
500 REM FORCE INTEGRATION TIME INTO SCRATCH PAD MEMORY
510 MOVE 32513 + 2 * I, 0: MOVE 32514 + 2 * I, 0
520 I = (J + F * G) * D
530 I = INT (L * 10 ^ 4 + .5) / INT (10 ^ 4 + .5)
540 PRINT CHR*(4);"FR#1"
550 PRINT ACTUAL INTEGRATION TIME WILL BE 0.018 SECONDS
560 PRINT CHR*(4);"FR#0"
570 PRINT CHR*(4);"BRUNMC10.0EJ0"

```

SOURCE FILE: MC10B

```

0000:          1 *****MC10B*****
0000:          2 *SET UP A SHORT INTEGRATION TIME FOR A SINGLE ARRAY
0000:          3 *PART OF PROGRAM FOR SETTING INTEGRATION TIMES FOR 6 ARRAYS
0000:          4 *THE BASIC PROGRAM HAS PREVIOUSLY POKED THE INTEGRATION TIMES
    INTO SCRATCH PAD MEMORY
----- NEXT OBJECT FILE NAME IS MC10B.OBJ0
9237:          5          ORG    $9237
9237:          6 *CLOSE THE GATE ON 8253 #1 COUNTER 0 DURING LOADING
9237:AD 58 C0    7          LDA    $C058
C000:          8 CLK     EQU    $C000
923A:          9 *FOR 8253 # 1
923A:A9 34    10         LDA    $34          ;LOAD MODE WORD COUNTER 0 MODE 2
923C:8D D3 C0 11         STA    CLK+3      ;LOAD INTO 8253 #1
923F:A9 50    12         LDA    $50          ;LOAD MODE WORD COUNTER 1 MODE 0
9241:8D D3 C0 13         STA    CLK+3      ;LOAD INTO 8253 #1
9244:A9 90    14         LDA    $90          ;LOAD MODE WORD COUNTER " MODE 2
9246:8D D3 C0 15         STA    CLK+3      ;LOAD INTO 8253 #1
9249:          16 *COUNTER #0 IN MODE 2 DIVIDES CLOCK RATE BY 3200
9249:A9 80    17         LDA    $80          ;LOAD COUNTER 0 LOW BYTE
924E:8D D0 C0 18         STA    CLK          ;WRITE LOW BYTE
924E:A9 0C    19         LDA    $0C          ;LOAD COUNTER 0 HIGH BYTE
9250:8D D0 C0 20         STA    CLK          ;WRITE HIGH BYTE
9253:          21 *COUNTERS #1 AND 2 OF 8253 #1 AND ALL 3 COUNTERS OF 8253 #2
9253:          22 *ARE IN MODE 0.THEY GATE COUNTERS #1 AND 2 OF 8253 #3 AND
9253:          23 *ALL 3 COUNTERS OF 8253 #4 THEREBY DELAYING THE START OF
9253:          24 *THEIR COUNTS
9253:A9 04    25         LDA    $04          ;LOAD COUNTER 1 LOW BYTE (ONLY)
9255:8D D1 C0 26         STA    CLK+1      ;WRITE LOW BYTE (ONLY)
9258:A9 09    27         LDA    $09          ;LOAD COUNTER 2 LOW BYTE (ONLY)
925A:8D D2 C0 28         STA    CLK+2      ;WRITE LOW BYTE (ONLY)
925D:          29 *FOR 8253 # 2
925D:A9 10    30         LDA    $10          ;LOAD MODE WORD COUNTER 0 MODE 0
925F:8D D7 C0 31         STA    CLK+7      ;LOAD INTO 8253 #2
9262:A9 50    32         LDA    $50          ;LOAD MODE WORD COUNTER 1 MODE 0
9264:8D D7 C0 33         STA    CLK+7      ;LOAD INTO 8253 #2
9267:A9 90    34         LDA    $90          ;LOAD MODE WORD COUNTER 2 MODE 0
9269:8D D7 C0 35         STA    CLK+7      ;LOAD INTO 8253 #2
926C:A9 0F    36         LDA    $0F          ;LOAD COUNTER 0 LOW BYTE (ONLY)
926E:8D D4 C0 37         STA    CLK+4      ;WRITE LOW BYTE (ONLY)
9271:A9 14    38         LDA    $14          ;LOAD COUNTER 1 LOW BYTE (ONLY)
9273:8D D5 C0 39         STA    CLK+5      ;WRITE LOW BYTE (ONLY)
9276:A9 19    40         LDA    $19          ;LOAD COUNTER 2 LOW BYTE (ONLY)
9278:8D D4 C0 41         STA    CLK+6      ;WRITE LOW BYTE (ONLY)
927E:          42 *8253'S #3 AND 4 CONTROL THE ACTUAL INTEGRATION TIMES.
927E:          43 *AFTER MODE WORDS ARE LOADED (ALL COUNTERS IN MODE 2)
927E:          44 *THE COUNTERS ARE LOADED WITH THEIR COUNTS FROM SCRATCH
927E:          45 *PAD MEMORY, WHERE THEY WERE PLACED BY THE BASIC PROGRAM
927E:A9 34    46         LDA    $34          ;LOAD MODE WORD COUNTER 0 MODE 2
927D:8D D8 C0 47         STA    CLK+$B      ;LOAD INTO 8253 #3
9280:A9 74    48         LDA    $74          ;LOAD MODE WORD COUNTER 1 MODE 2
9282:8D D8 C0 49         STA    CLK+$B      ;LOAD INTO 8253 #3
9285:A9 B4    50         LDA    $B4          ;LOAD MODE WORD COUNTER 2 MODE 2
9287:8D D8 C0 51         STA    CLK+$B      ;LOAD INTO 8253 #3
928A:AD 01 7F 52         LDA    $7F01      ;FETCH LOW BYTE 1ST INTEGRATION TIME
928D:8D D8 C0 53         STA    CLK+8      ;WRITE LOW BYTE
9290:AD 02 7F 54         LDA    $7F02      ;FETCH HIGH BYTE 1ST INTEGRATION TIME
9293:8D D8 C0 55         STA    CLK+8      ;WRITE HIGH BYTE
9296:AD 03 7F 56         LDA    $7F03      ;FETCH LOW BYTE 2ND INTEGRATION TIME
9299:8D D9 C0 57         STA    CLK+9      ;WRITE LOW BYTE
929C:AD 04 7F 58         LDA    $7F04      ;FETCH HIGH BYTE 2ND INTEGRATION TIME

```

929F:8D D9 C0	59	STA CLK+9	;WRITE HIGH BYTE
92A2:AD 05 7F	60	LDA \$7F05	;FETCH LOW BYTE 3RD INTEGRATION TIME
92A5:8D DA C0	61	STA CLK+\$A	;WRITE LOW BYTE
92A8:AD 06 7F	62	LDA \$7F06	;FETCH HIGH BYTE 3RD INTEGRATION TIME
92AB:8D DA C0	63	STA CLK+\$A	;WRITE HIGH BYTE
92AE:A9 34	64	LDA \$B34	;LOAD MODE WORD COUNTER 0 MODE 2
92B0:8D DF C0	65	STA CLK+\$F	;LOAD INTO 8253 #4
92B3:A9 74	66	LDA \$B74	;LOAD MODE WORD COUNTER 0 MODE2
92B5:8D DF C0	67	STA CLK+\$F	;LOAD INTO 8253 #4
92B8:A9 B4	68	LDA \$BB4	;LOAD MODE WORD COUNTER 0 MODE 2
92BA:8D DF C0	69	STA CLK+\$F	;LOAD INTO 8253 #4
92BD:AD 07 7F	70	LDA \$7F07	;FETCH LOW BYTE 4TH INTEGRATION TIME
92C0:8D DC C0	71	STA CLK+\$C	;WRITE LOW BYTE
92C3:AD 08 7F	72	LDA \$7F08	;FETCH HIGH BYTE 4TH INTEGRATION TIME
92C6:8D DC C0	73	STA CLK+\$C	;WRITE HIGH BYTE
92C9:AD 09 7F	74	LDA \$7F09	;FETCH LOW BYTE 5TH INTEGRATION TIME
92CC:8D DD C0	75	STA CLK+\$D	;WRITE LOW BYTE
92CF:AD 0A 7F	76	LDA \$7F0A	;FETCH HIGH BYTE 5TH INTEGRATION TIME
92D2:8D DD C0	77	STA CLK+\$D	;WRITE HIGH BYTE
92D5:AD 0B 7F	78	LDA \$7F0B	;FETCH LOW BYTE 6TH INTEGRATION TIME
92D8:8D DE C0	79	STA CLK+\$E	;WRITE LOW BYTE
92DB:AD 0C 7F	80	LDA \$7F0C	;FETCH HIGH BYTE 6TH INTEGRATION TIME
92DE:8D DE C0	81	STA CLK+\$E	;WRITE HIGH BYTE
92E1:EA	82	NOP	
92E2:EA	83	NOP	
92E3:EA	84	NOP	
92E4:	85	*ALL COUNTERS LOADED SO OPEN THE GATE ON 8253 #1 COUNTER 0	
92E4:AD 59 C0	86	LDA \$C059	
92E7:60	87	RTS	;GO AND DO SOMETHING ELSE

```

SOURCE FILE: MC10
----- NEXT OBJECT FILE NAME IS MC10.OBJ0
9205: 1 ORG $9205
9205: 2 *PROGRAM TO PUT DEFAULT VALUES IN SCRATCH PAD MEMORY
9205: 3 *LOAD BOTH BYTES WITH MAXIMUM (=0)
9205:A9 00 4 LDA $B00 ;LOAD LOW BYTE
9207:8D 01 7F 5 STA $7F01
920A:8D 03 7F 6 STA $7F03
920D:8D 05 7F 7 STA $7F05
9210:8D 07 7F 8 STA $7F07
9213:8D 09 7F 9 STA $7F09
9216:8D 0B 7F 10 STA $7F0B
9219:A9 00 11 LDA $B00 ;LOAD HIGH BYTE
921B:8D 02 7F 12 STA $7F02
921E:8D 04 7F 13 STA $7F04
9221:8D 06 7F 14 STA $7F06
9224:8D 08 7F 15 STA $7F08
9227:8D 0A 7F 16 STA $7F0A
922A:8D 0C 7F 17 STA $7F0C
922D:60 18 RTS ;FINISHED
    
```

SEL4 is used to subtract 2 sets of data values. If necessary it calculates the mean values first. It can take its data from the RAM data files or can load it from disk storage. Before doing the subtraction, it checks for matching of the gain code of the A/DC and the integration time used for each array and aborts if it finds a mismatch.

TEST.OBJ0 is just a dummy program that acts as a switch, changing the drive response from drive #2, the data disk, back to drive #1, for the system disk.

MC6A transfers replication and gain data to the Background Means File from the Background Raw Data File.

MC7.OBJ0 is the binary subtraction program.

```

10 REM PROGRAM **SEL4**
20 HIMEM: 29439
30 GOTO 280
40 REM BACKGROUND SUBTRACTION PROGRAM
50 REM SUBROUTINE TO CALCULATE MEANS FROM DATA IN THE INPUT BUFFER
60 REM OR BACKGROUND RAW DATA FILE AND STORE THEM IN THE ANALYTE OR BACKGROUND
70 REM MEANS FILE
80 PRINT
90 B = 128:C = 768:D = 1536:S = 256
100 AA = A
110 REM ONE ARRAY AT A TIME
120 FOR I = 0 TO 5
130 W = F + I * B:X = W + C
140 A = AA + I * B:K = A + C:L = A + D:M = PEEK (E + I)
150 REM CHECK THE REPLICATE COUNT,IF ZERO IGNORE THIS ARRAY
160 IF M = 0 THEN 260
170 FOR N = 0 TO 127
180 Q = PEEK (A + N):R = PEEK (K + N):S = PEEK (L + N)
190 REM READ THE DATA FILE IN DECIMAL
200 R = ((Q * S + P) * S + Q) / M:T = INT (R / S)
210 REM DIVIDE BY THE REPLICATE COUNT AND PUT IT BACK IN A
220 REM TWO BYTE BINARY FORM
230 U = INT (R - S * T)
240 POKE W + N,U: POKE X + N,T
250 NEXT N
260 NEXT I
270 RETURN
280 HOME
290 INVERSE : HTAB 4: PRINT "BACKGROUND SUBTRACTION OPTION": NORMAL
300 PRINT "THIS OPTION SUBTRACTS ONE SET OF DATA POINT MEANS FROM ANOTHER SET
310 PRINT
320 HTAB 15: INVERSE : PRINT "WARNING": NORMAL
330 PRINT
340 PRINT "THIS PROGRAM OVERWRITES THE INPUT BUFFER"
350 PRINT "IF YOU WISH TO KEEP IT'S CONTENTS AS RAW"
360 PRINT "DATA, ABORT THIS PROGRAM NOW AND SAVE "
370 PRINT
380 PRINT "THE BUFFER ON DISKETTE FIRST"
390 PRINT "*****"
400 FOR X = 1 TO 4000: NEXT X
410 PRINT "WHERE IS THE BACKGROUND DATA ?"
420 PRINT
430 PRINT "1. IN THE INPUT DATA BUFFER ?"
440 PRINT
450 PRINT "2. IN THE BACKGROUND RAW DATA FILE ?"
460 PRINT
470 PRINT "3. IN THE BACKGROUND MEANS FILE ?"
480 PRINT
490 PRINT "4. ON DISK AS RAW DATA ?"
500 PRINT
510 PRINT "5. ON DISK AS MEANS ?"
520 PRINT
530 INPUT "ENTER 1,2,3,4 OR 5 :";A$
540 HOME
550 PRINT "WHERE IS THE ANALYTE DATA ?"
560 PRINT
570 PRINT "1. IN THE INPUT BUFFER ?"
580 PRINT
590 PRINT "2. IN THE ANALYTE MEANS FILE ?"
600 PRINT

```

```

610 PRINT "3. ON DISK AS RAW DATA ?"
620 PRINT
630 PRINT "4. ON DISK AS MEANS ? "
640 PRINT
650 INPUT "ENTER 1,2,3 OR 4 ";B$
660 ON VAL (A$) GOTO 680,720,750,760,840
670 PRINT
680 A = 32768:E = 32531:F = 29440
690 GOSUB 80
700 PRINT CHR$(4);"BRUNMC6.OBJ0"
710 GOTO 890
720 A = 35072:E = 32568:F = 29440
730 GOSUB 80
740 PRINT CHR$(4);"BRUNMC6A.OBJ0"
750 GOTO 890
760 INPUT "ENTER BACKGROUND FILE NAME ";F$
770 G$ = F$ + "Z"
780 PRINT CHR$(4);"BLOAD";F$;"",D2,A$8900"
790 PRINT CHR$(4);"BLOAD";G$;"",A$7F26"
800 A = 35072:E = 32568:F = 29440
810 GOSUB 80
820 PRINT CHR$(4);"BRUNMC6A.OBJ0,D1"
830 GOTO 890
840 INPUT "ENTER BACKGROUND FILE NAME ";F$
850 G$ = F$ + "Z"
860 PRINT CHR$(4);"BLOAD";F$;"",D2,A$7300"
870 PRINT CHR$(4);"BLOAD";G$;"",A$7F56"
880 PRINT CHR$(4);"BLOADTEST,D1"
890 ON VAL (B$) GOTO 900,930,940,1020
900 A = 32768:E = 32531:F = 30976
910 GOSUB 80
920 PRINT CHR$(4);"BRUNMC5.OBJ0"
930 GOTO 1070
940 INPUT "ENTER ANALYTE FILE NAME ";F$
950 G$ = F$ + "Z"
960 PRINT CHR$(4);"BLOAD";F$;"",D2,A$8000"
970 PRINT CHR$(4);"BLOAD";G$;"",A$7F01"
980 A = 32768:E = 32531:F = 30976
990 GOSUB 80
1000 PRINT CHR$(4);"BRUNMC5.OBJ0,D1"
1010 GOTO 1070
1020 INPUT "ENTER ANALYTE FILE NAME ";F$
1030 G$ = F$ + "Z"
1040 PRINT CHR$(4);"BLOAD";F$;"",D2,A$7900"
1050 PRINT CHR$(4);"BLOAD";G$;"",A$7F3E"
1060 PRINT CHR$(4);"BLOADTEST,D1"
1070 REM NOW THAT THE FILES ARE IN THEIR PROPER LOCATIONS THEY MUST BE TESTED
1080 REM TO SEE IF SUBTRACTION WOULD BE LEGITIMATE
1090 H = 32586:J = 32610
1100 FOR I = 0 TO 5:G = PEEK (H + I) - PEEK (J + I)
1110 IF G = 0 GOTO 1140
1120 FLASH : PRINT "ARRAY ";I;"GAINS DO NOT MATCH": NORMAL
1130 PRINT CHR$(4);"RUNDRS"
1140 H = 32574:J = 32598
1150 FOR I = 0 TO 5:G = PEEK (H + 2 * I) - PEEK (J + 2 * I)
1160 V = PEEK (H + 2 * I + 1) - PEEK (J + 2 * I + 1)
1170 IF G < > 0 GOTO 1200
1180 IF V < > 0 GOTO 1200
1190 GOTO 1220
1200 FLASH : PRINT "INTEGRATION TIMES DO NOT MATCH": NORMAL

```

```

1210 PRINT CHR$(4);"RUNDRS"
1220 NEXT I
1230 REM AS ALL IS WELL DO THE SUBTRACTION
1240 PRINT CHR$(4);"BRUNMC7.OBJ0"
1250 E = 32531: FOR I = 0 TO 5: POKE E + I,1: NEXT I
1260 REM DIFFERENCES ARE STORED IN INPUT BUFFER.REPLICATION VALUE
1270 REM REDUCED TO 1 TO AVOID PROBLEMS
1280 HOME
1290 PRINT "BACKGROUND SUBTRACTED VALUES ARE"
1300 PRINT
1310 PRINT "IN THE INPUT BUFFER IN BINARY"
1320 PRINT
1330 INVERSE : PRINT "THERE WILL BE OVERSUBTRACTION DUE TO"
1340 PRINT
1350 PRINT "NOISE.THIS MUST BE CORRECTED FOR IN"
1360 PRINT
1370 PRINT "THE READOUT OPTIONS"
1380 PRINT
1390 NORMAL
1400 PRINT "CHOOSE:-"
1410 PRINT
1420 PRINT "1. STORE ON DISKETTE"
1430 PRINT
1440 PRINT "2. OUTPUT USING AN OPTION ON THE"
1450 HTAB 4: PRINT "MAIN MENU"
1460 PRINT
1470 INPUT "CHOOSE 1 OR 2 ";K$
1480 ON VAL (K$) GOTO 1490,1550
1490 HOME
1500 INPUT "ENTER FILE NAME":F$
1510 G$ = F$ + ".Z"
1520 PRINT CHR$(4);"SAVED":F$;"",D2,A$8000,L$600"
1530 PRINT CHR$(4);"SAVED":G$;"",A$7F01,L$18"
1540 GOTO 1360
1550 PRINT CHR$(4);"RUNDRS,D1"

```

## SOURCE FILE: TEST

----- NEXT OBJECT FILE NAME IS TEST.OBJ0

```

95F8:          1          ORG  $95F8
95F8:          2 *TEST-A PROGRAM THAT ACOMPLISHES NOTHING BUT IS USED IN A
95F8:          3 *DOS COMMAND TO SWITCH DISK DRIVES
95F8:AD FF 95   4          LDA  $95FF
95FE:BD FF 95   5          STA  $95FF
95FE:60        6          RTS

```

## SOURCE FILE: MC6A

----- NEXT OBJECT FILE NAME IS MC6A.OBJ0

```

9200:          1          ORG  $9200
9200:          2 *TRANSFER REPLICATION AND GAIN DATA
9200:          3 *FOR THE BACKGROUND MEANS FILE
9200:          4 *FROM THE BACKGROUND RAW DATA FILE
9200:A2 17      5          LDX  $$17
9202:ED 26 7F  6 BR1     LDA  $7F26,X
9205:9D 56 7F  7          STA  $7F56,X
9208:CA        8          DEX
9209:10 FT     9          EPL  BR1
920E:60       10         RTS

```

SOURCE FILE: MC7

----- NEXT OBJECT FILE NAME IS MC7,OBJO

```

9200:          1      ORG  $9200
9200:          2  *PROGRAM SUBTRACTS THE TWO BYTE VALUES IN THE BACKGROUND
9200:          3  *MEANS FILE FROM THE TWO BYTE VALUES IN THE ANALYTE MEANS
9200:          4  *FILE AND STORES THE RESULT IN THE INPUT BUFFER
9200:08        5      CLD
9201:A2 00     6      LDX  $600
9203:38        7  BR1   SEC
9204:BD 00 79  8      LDA  $7900,X
9207:FD 00 73  9      SBC  $7300,X
920A:9D 00 80 10     STA  $8000,X
920D:BD 00 7C 11     LDA  $7C00,X
9210:FD 00 76 12     SBC  $7600,X
9213:9D 00 83 13     STA  $8300,X
9216:38        14     SEC
9217:ED 00 7A 15     LDA  $7A00,X
921A:FD 00 74 16     SBC  $7400,X
921D:9D 00 81 17     STA  $8100,X
9220:ED 00 7D 18     LDA  $7D00,X
9223:FD 00 77 19     SBC  $7700,X
9226:9D 00 84 20     STA  $8400,X
9229:38        21     SEC
922A:BD 00 7B 22     LDA  $7B00,X
922D:FD 00 75 23     SBC  $7500,X
9230:9D 00 82 24     STA  $8200,X
9233:BD 00 7E 25     LDA  $7E00,X
9236:FD 00 78 26     SBC  $7800,X
9239:9D 00 85 27     STA  $8500,X
923C:CA        28     DEX
923D:D0 C4     29     BNE  BR1
923F:          30  *NOW COPY THE INTEGRATION TIME,GAIN AND REPLICATION PARAMETER
S
923F:          31  *TO THE CORRESPONDING ADDRESSES FOR THE INPUT BUFFER
923F:A2 17     32     LDX  $17
9241:ED 3E 7F 33  BR2   LDA  $7F3E,X
9244:9D 01 7F 34     STA  $7F01,X
9247:CA        35     DEX
9248:10 F7     36     BPL  BR2
924A:60        37     RTS

```

;BACK TO BASIC

SEL5 is the graphics program. It allows display of the contents of a data file, array by array, on the video monitor. It can accept data from a disk. If the data file is the result of a subtraction and involves a bipolar A/DC setting (for example,  $\pm 0.5$  V) it adds an offset value to recentre the spectrum. The program contains unlisted control characters which can be seen by first running a special decode program given in the Apple literature [60] and then loading the program from disk and listing it. The characters printed in lines 1040 to 1080 and 1130 are actually index marks on the graph abscissa and ordinate (the HTAP function does not quite match the required spacing of the abscissa index marks in high resolution graphics).

The program allows the video display to include a title and this version also displays the integration time, calculated from scratch pad memory values.

The display can be put out to a printer. The format for the display is shown in Figure 60.

One problem with the program is that on a high resolution graphics are in use, the only way to leave the and return to standard text display is by pressing `CTRL`. This unfortunately cancels the operation of the integration timers so they have to be reloaded through `SET`.

```

10 REM PROGRAM **SEL5** CONTAINS UNLISTED CONTROL CHARACTERS
20 HIMEM: 29439
30 REM PROGRAM TO DISPLAY THE SIGNALS GRAPHICALLY ON THIS SCREEN
40 HOME
50 V = 0
60 REM SET FLAG FOR HIRES CHAR SET TO BE LOADED
70 OS = 0
80 PRINT "THIS OPTION DISPLAYS THE OUTPUTS FOR ALL 128 DIODES OF A SELECTED ARR
AY ON THIS SCREEN"
90 PRINT : PRINT : PRINT "DATA CAN BE:--"
100 PRINT "1. SINGLE RUN IN THE INPUT BUFFER"
110 PRINT : PRINT "2. SINGLE RUN IN THE INPUT BUFFER"
120 HTAB 4: PRINT "FILE"
130 PRINT : PRINT "3. SUBTRACTED MEAN VALUES STORED"
140 HTAB 4: PRINT "IN THE INPUT BUFFER"
150 PRINT : PRINT "4. ANALYTE SIGNAL MEANS": PRINT
160 PRINT "5. BACKGROUND MEAN VALUES"
170 PRINT : PRINT "6. FROM A DISKETTE IN DRIVE #?": PRINT
180 PRINT
190 INPUT "ENTER 1,2,3,4,5 OR 6 ";E$
200 ON VAL (E$) GOTO 220,230,240,250,260,270
210 REM F=BASE ADDRESS FOR THE GAIN CODES AND G=BASE ADDRESS FOR THE DATA
220 F = 32525:G = 32768: GOTO 340
230 F = 32562:G = 35072: GOTO 340
240 F = 32525:G = 32768:OS = 2048: GOTO 340
250 F = 32586:G = 30976: GOTO 340
260 F = 32610:G = 29440: GOTO 340
270 INPUT "ENTER FILE NAME ";F$
280 REM LOAD FROM DISKETTE TO INPUT BUFFER
290 C$ = F$ + ".Z"
300 PRINT CHR$(4);"ELOAD";F$;" ,D2,A$8000"
310 PRINT CHR$(4);"ELOAD";G$;" ,A$7E01"
320 PRINT CHR$(4);"ELOADTEST.C1"
330 F = 32525:G = 32768
340 N = 256
350 IF V = 0 THEN GOSUB 650
360 GOSUB 790
370 REM LOAD CHARACTER SETS FOR HIGH RESOLUTION GRAPHICS
380 GOSUB 920
390 REM IDENTIFY INDIVIDUAL ARRAY AND DECODE GAIN CODE
400 R$ = "0"
410 REM RUN THE DISPLAY
420 PRINT B$
430 CALL - 756
440 PRINT : PRINT "CHOOSE ONE OF THE FOLLOWING": PRINT
450 HTAB 4: PRINT "1. MAKE A PRINTED COPY OF THE GRAPH"
460 PRINT : HTAB 4: PRINT "2. LOOK AT ANOTHER ARRAY IN THE SAME"
470 HTAB 4: PRINT "3. LOOK AT ANOTHER FILE"
480 PRINT : PRINT "4. LOAD FROM DISKETTE"
490 PRINT
500 INPUT " ";
510 PRINT
520 PRINT
530 PRINT
540 PRINT
550 IF 7 > 1 THEN 1350
560 R$ = "C"
570 REM Z=G FOR GRAPHICS
580 GOSUB 120

```

```

600 PRINT CHR$(9);Z$
610 PRINT CHR$(4)"FR#0"
620 CALL ADRS
630 GOTO 400
640 REM PROGRAM TO LOAD HRCC
650 ADRS = 0
660 PRINT CHR$(4);"BLOAD REBOOT"
670 CALL 520: REM EXECUTE REBOOT
680 ADRS = USR(0),"HRCC"
690 REM BRING IN HRCC, ADRS=STARTING ADDRESS
700 IF ADRS < = 0 THEN ADRS = ADRS + 65536: REM MAKE ADRS POSITIVE
710 CS = ADRS - 768: HIMEM: CS
720 CH = INT (CS / 256): CL = CS - 256 * CH
730 POKE ADRS + 7,CL: POKE ADRS + 8,CH
740 PRINT CHR$(4);"BLOADA.SET,A";CS
750 REM SET.A IS A MODIFIED ASCII SET WITH INDEX MARKS AS SPECIAL CHARACTERS
760 V = 1
770 REM SET FLAG TO SHOW HTRES CHAR SET IS LOADED
780 RETURN
790 INPUT "ENTER ARRAY # ( 0 TO 5 ) ";I
800 REM DECODE GAIN CODE FOR ARRAY TO GET CONSTANTS FOR THE D DELAY ORDINATE
810 W = 1:D = 3.1289E - 3:A1 = 12:H = PEEK ( - A1 + I + 1 ) + I * PEEK ( - A1
+ I + I + W):H2 = H * D:H3 = INT (H2 * 10 ^ 4) / 10 ^ 4
820 INPUT "ENTER TITLE ";A$
830 J = PEEK ( I + 1 ):K = INT ( J / 10 )
840 L = K - INT ( K / 10 ) * 10
850 IF L = 0 THEN B = 5
860 IF L = 1 THEN B = 1
870 IF L = 2 THEN B = 0.5
880 IF L = 3 THEN B = 0.1
890 C = 0: IF K > 3 THEN C = 1
900 IF K < 4 THEN DS = 0
910 RETURN
920 CALL ADRS: REM INITIALIZE HRCC
930 HGR : POKE 170,11
940 HCOLOR= 3
950 REM SWITCH TO HIGH RESOLUTION
960 H$LOT 23 27 1
970 "$ = "1"
980 REM DRAW AXES
990 PRINT A$
1000 REM CALL CHARACTER SET
1010 VTAB 2: HTAB 4: PRINT "1"
1020 HTAB 6: PRINT "2"
1030 = 2
1040 VTAB 4: HTAB 4: PRINT "3"
1050 VTAB 6: HTAB 6: PRINT "4"
1060 VTAB 8: HTAB 8: PRINT "5"
1070 VTAB 10: HTAB 10: PRINT "6"
1080 VTAB 12: HTAB 12: PRINT "7"
1090 REM PRINT THE INDEX MARKS FOR THE AFS I
1100 FOR A = 0 TO 9: VTAB ( A + 1 ): HTAB ( A + 1 ): PRINT A
1110 HTAB 6: PRINT "6"
: VTAB 10: PRINT "S"
1120 REM LABEL THE ORDINATE
1130 FOR B = 1 TO 8: HTAB ( B ): VTAB ( B ): PRINT B
1140 REM PRINT THE INDEX MARKS FOR THE X
1150 C = 1
1160 VTAB 10: HTAB 4: PRINT "0"
1170 VTAB 10: HTAB 6: PRINT "1"
1180 VTAB 10: HTAB 8: PRINT "2"
1190 VTAB 10: HTAB 10: PRINT "3"
1200 VTAB 10: HTAB 12: PRINT "4"
1210 VTAB 10: HTAB 14: PRINT "5"
1220 VTAB 10: HTAB 16: PRINT "6"
1230 VTAB 10: HTAB 18: PRINT "7"
1240 VTAB 10: HTAB 20: PRINT "8"
1250 VTAB 10: HTAB 22: PRINT "9"
1260 VTAB 10: HTAB 24: PRINT "A"
1270 VTAB 10: HTAB 26: PRINT "B"
1280 VTAB 10: HTAB 28: PRINT "C"
1290 VTAB 10: HTAB 30: PRINT "D"
1300 VTAB 10: HTAB 32: PRINT "E"
1310 VTAB 10: HTAB 34: PRINT "F"
1320 VTAB 10: HTAB 36: PRINT "G"
1330 VTAB 10: HTAB 38: PRINT "H"
1340 VTAB 10: HTAB 40: PRINT "I"
1350 VTAB 10: HTAB 42: PRINT "J"
1360 VTAB 10: HTAB 44: PRINT "K"
1370 VTAB 10: HTAB 46: PRINT "L"
1380 VTAB 10: HTAB 48: PRINT "M"
1390 VTAB 10: HTAB 50: PRINT "N"
1400 VTAB 10: HTAB 52: PRINT "O"
1410 VTAB 10: HTAB 54: PRINT "P"
1420 VTAB 10: HTAB 56: PRINT "Q"
1430 VTAB 10: HTAB 58: PRINT "R"
1440 VTAB 10: HTAB 60: PRINT "S"
1450 VTAB 10: HTAB 62: PRINT "T"
1460 VTAB 10: HTAB 64: PRINT "U"
1470 VTAB 10: HTAB 66: PRINT "V"
1480 VTAB 10: HTAB 68: PRINT "W"
1490 VTAB 10: HTAB 70: PRINT "X"
1500 VTAB 10: HTAB 72: PRINT "Y"
1510 VTAB 10: HTAB 74: PRINT "Z"
1520 VTAB 10: HTAB 76: PRINT "A"
1530 VTAB 10: HTAB 78: PRINT "B"
1540 VTAB 10: HTAB 80: PRINT "C"
1550 VTAB 10: HTAB 82: PRINT "D"
1560 VTAB 10: HTAB 84: PRINT "E"
1570 VTAB 10: HTAB 86: PRINT "F"
1580 VTAB 10: HTAB 88: PRINT "G"
1590 VTAB 10: HTAB 90: PRINT "H"
1600 VTAB 10: HTAB 92: PRINT "I"
1610 VTAB 10: HTAB 94: PRINT "J"
1620 VTAB 10: HTAB 96: PRINT "K"
1630 VTAB 10: HTAB 98: PRINT "L"
1640 VTAB 10: HTAB 100: PRINT "M"
1650 VTAB 10: HTAB 102: PRINT "N"
1660 VTAB 10: HTAB 104: PRINT "O"
1670 VTAB 10: HTAB 106: PRINT "P"
1680 VTAB 10: HTAB 108: PRINT "Q"
1690 VTAB 10: HTAB 110: PRINT "R"
1700 VTAB 10: HTAB 112: PRINT "S"
1710 VTAB 10: HTAB 114: PRINT "T"
1720 VTAB 10: HTAB 116: PRINT "U"
1730 VTAB 10: HTAB 118: PRINT "V"
1740 VTAB 10: HTAB 120: PRINT "W"
1750 VTAB 10: HTAB 122: PRINT "X"
1760 VTAB 10: HTAB 124: PRINT "Y"
1770 VTAB 10: HTAB 126: PRINT "Z"
1780 VTAB 10: HTAB 128: PRINT "A"
1790 VTAB 10: HTAB 130: PRINT "B"
1800 VTAB 10: HTAB 132: PRINT "C"
1810 VTAB 10: HTAB 134: PRINT "D"
1820 VTAB 10: HTAB 136: PRINT "E"
1830 VTAB 10: HTAB 138: PRINT "F"
1840 VTAB 10: HTAB 140: PRINT "G"
1850 VTAB 10: HTAB 142: PRINT "H"
1860 VTAB 10: HTAB 144: PRINT "I"
1870 VTAB 10: HTAB 146: PRINT "J"
1880 VTAB 10: HTAB 148: PRINT "K"
1890 VTAB 10: HTAB 150: PRINT "L"
1900 VTAB 10: HTAB 152: PRINT "M"
1910 VTAB 10: HTAB 154: PRINT "N"
1920 VTAB 10: HTAB 156: PRINT "O"
1930 VTAB 10: HTAB 158: PRINT "P"
1940 VTAB 10: HTAB 160: PRINT "Q"
1950 VTAB 10: HTAB 162: PRINT "R"
1960 VTAB 10: HTAB 164: PRINT "S"
1970 VTAB 10: HTAB 166: PRINT "T"
1980 VTAB 10: HTAB 168: PRINT "U"
1990 VTAB 10: HTAB 170: PRINT "V"
2000 VTAB 10: HTAB 172: PRINT "W"
2010 VTAB 10: HTAB 174: PRINT "X"
2020 VTAB 10: HTAB 176: PRINT "Y"
2030 VTAB 10: HTAB 178: PRINT "Z"
2040 VTAB 10: HTAB 180: PRINT "A"
2050 VTAB 10: HTAB 182: PRINT "B"
2060 VTAB 10: HTAB 184: PRINT "C"
2070 VTAB 10: HTAB 186: PRINT "D"
2080 VTAB 10: HTAB 188: PRINT "E"
2090 VTAB 10: HTAB 190: PRINT "F"
2100 VTAB 10: HTAB 192: PRINT "G"
2110 VTAB 10: HTAB 194: PRINT "H"
2120 VTAB 10: HTAB 196: PRINT "I"
2130 VTAB 10: HTAB 198: PRINT "J"
2140 VTAB 10: HTAB 200: PRINT "K"
2150 VTAB 10: HTAB 202: PRINT "L"
2160 VTAB 10: HTAB 204: PRINT "M"
2170 VTAB 10: HTAB 206: PRINT "N"
2180 VTAB 10: HTAB 208: PRINT "O"
2190 VTAB 10: HTAB 210: PRINT "P"
2200 VTAB 10: HTAB 212: PRINT "Q"
2210 VTAB 10: HTAB 214: PRINT "R"
2220 VTAB 10: HTAB 216: PRINT "S"
2230 VTAB 10: HTAB 218: PRINT "T"
2240 VTAB 10: HTAB 220: PRINT "U"
2250 VTAB 10: HTAB 222: PRINT "V"
2260 VTAB 10: HTAB 224: PRINT "W"
2270 VTAB 10: HTAB 226: PRINT "X"
2280 VTAB 10: HTAB 228: PRINT "Y"
2290 VTAB 10: HTAB 230: PRINT "Z"
2300 VTAB 10: HTAB 232: PRINT "A"
2310 VTAB 10: HTAB 234: PRINT "B"
2320 VTAB 10: HTAB 236: PRINT "C"
2330 VTAB 10: HTAB 238: PRINT "D"
2340 VTAB 10: HTAB 240: PRINT "E"
2350 VTAB 10: HTAB 242: PRINT "F"
2360 VTAB 10: HTAB 244: PRINT "G"
2370 VTAB 10: HTAB 246: PRINT "H"
2380 VTAB 10: HTAB 248: PRINT "I"
2390 VTAB 10: HTAB 250: PRINT "J"
2400 VTAB 10: HTAB 252: PRINT "K"
2410 VTAB 10: HTAB 254: PRINT "L"
2420 VTAB 10: HTAB 256: PRINT "M"
2430 VTAB 10: HTAB 258: PRINT "N"
2440 VTAB 10: HTAB 260: PRINT "O"
2450 VTAB 10: HTAB 262: PRINT "P"
2460 VTAB 10: HTAB 264: PRINT "Q"
2470 VTAB 10: HTAB 266: PRINT "R"
2480 VTAB 10: HTAB 268: PRINT "S"
2490 VTAB 10: HTAB 270: PRINT "T"
2500 VTAB 10: HTAB 272: PRINT "U"
2510 VTAB 10: HTAB 274: PRINT "V"
2520 VTAB 10: HTAB 276: PRINT "W"
2530 VTAB 10: HTAB 278: PRINT "X"
2540 VTAB 10: HTAB 280: PRINT "Y"
2550 VTAB 10: HTAB 282: PRINT "Z"
2560 VTAB 10: HTAB 284: PRINT "A"
2570 VTAB 10: HTAB 286: PRINT "B"
2580 VTAB 10: HTAB 288: PRINT "C"
2590 VTAB 10: HTAB 290: PRINT "D"
2600 VTAB 10: HTAB 292: PRINT "E"
2610 VTAB 10: HTAB 294: PRINT "F"
2620 VTAB 10: HTAB 296: PRINT "G"
2630 VTAB 10: HTAB 298: PRINT "H"
2640 VTAB 10: HTAB 300: PRINT "I"
2650 VTAB 10: HTAB 302: PRINT "J"
2660 VTAB 10: HTAB 304: PRINT "K"
2670 VTAB 10: HTAB 306: PRINT "L"
2680 VTAB 10: HTAB 308: PRINT "M"
2690 VTAB 10: HTAB 310: PRINT "N"
2700 VTAB 10: HTAB 312: PRINT "O"
2710 VTAB 10: HTAB 314: PRINT "P"
2720 VTAB 10: HTAB 316: PRINT "Q"
2730 VTAB 10: HTAB 318: PRINT "R"
2740 VTAB 10: HTAB 320: PRINT "S"
2750 VTAB 10: HTAB 322: PRINT "T"
2760 VTAB 10: HTAB 324: PRINT "U"
2770 VTAB 10: HTAB 326: PRINT "V"
2780 VTAB 10: HTAB 328: PRINT "W"
2790 VTAB 10: HTAB 330: PRINT "X"
2800 VTAB 10: HTAB 332: PRINT "Y"
2810 VTAB 10: HTAB 334: PRINT "Z"
2820 VTAB 10: HTAB 336: PRINT "A"
2830 VTAB 10: HTAB 338: PRINT "B"
2840 VTAB 10: HTAB 340: PRINT "C"
2850 VTAB 10: HTAB 342: PRINT "D"
2860 VTAB 10: HTAB 344: PRINT "E"
2870 VTAB 10: HTAB 346: PRINT "F"
2880 VTAB 10: HTAB 348: PRINT "G"
2890 VTAB 10: HTAB 350: PRINT "H"
2900 VTAB 10: HTAB 352: PRINT "I"
2910 VTAB 10: HTAB 354: PRINT "J"
2920 VTAB 10: HTAB 356: PRINT "K"
2930 VTAB 10: HTAB 358: PRINT "L"
2940 VTAB 10: HTAB 360: PRINT "M"
2950 VTAB 10: HTAB 362: PRINT "N"
2960 VTAB 10: HTAB 364: PRINT "O"
2970 VTAB 10: HTAB 366: PRINT "P"
2980 VTAB 10: HTAB 368: PRINT "Q"
2990 VTAB 10: HTAB 370: PRINT "R"
3000 VTAB 10: HTAB 372: PRINT "S"
3010 VTAB 10: HTAB 374: PRINT "T"
3020 VTAB 10: HTAB 376: PRINT "U"
3030 VTAB 10: HTAB 378: PRINT "V"
3040 VTAB 10: HTAB 380: PRINT "W"
3050 VTAB 10: HTAB 382: PRINT "X"
3060 VTAB 10: HTAB 384: PRINT "Y"
3070 VTAB 10: HTAB 386: PRINT "Z"
3080 VTAB 10: HTAB 388: PRINT "A"
3090 VTAB 10: HTAB 390: PRINT "B"
3100 VTAB 10: HTAB 392: PRINT "C"
3110 VTAB 10: HTAB 394: PRINT "D"
3120 VTAB 10: HTAB 396: PRINT "E"
3130 VTAB 10: HTAB 398: PRINT "F"
3140 VTAB 10: HTAB 400: PRINT "G"
3150 VTAB 10: HTAB 402: PRINT "H"
3160 VTAB 10: HTAB 404: PRINT "I"
3170 VTAB 10: HTAB 406: PRINT "J"
3180 VTAB 10: HTAB 408: PRINT "K"
3190 VTAB 10: HTAB 410: PRINT "L"
3200 VTAB 10: HTAB 412: PRINT "M"
3210 VTAB 10: HTAB 414: PRINT "N"
3220 VTAB 10: HTAB 416: PRINT "O"
3230 VTAB 10: HTAB 418: PRINT "P"
3240 VTAB 10: HTAB 420: PRINT "Q"
3250 VTAB 10: HTAB 422: PRINT "R"
3260 VTAB 10: HTAB 424: PRINT "S"
3270 VTAB 10: HTAB 426: PRINT "T"
3280 VTAB 10: HTAB 428: PRINT "U"
3290 VTAB 10: HTAB 430: PRINT "V"
3300 VTAB 10: HTAB 432: PRINT "W"
3310 VTAB 10: HTAB 434: PRINT "X"
3320 VTAB 10: HTAB 436: PRINT "Y"
3330 VTAB 10: HTAB 438: PRINT "Z"
3340 VTAB 10: HTAB 440: PRINT "A"
3350 VTAB 10: HTAB 442: PRINT "B"
3360 VTAB 10: HTAB 444: PRINT "C"
3370 VTAB 10: HTAB 446: PRINT "D"
3380 VTAB 10: HTAB 448: PRINT "E"
3390 VTAB 10: HTAB 450: PRINT "F"
3400 VTAB 10: HTAB 452: PRINT "G"
3410 VTAB 10: HTAB 454: PRINT "H"
3420 VTAB 10: HTAB 456: PRINT "I"
3430 VTAB 10: HTAB 458: PRINT "J"
3440 VTAB 10: HTAB 460: PRINT "K"
3450 VTAB 10: HTAB 462: PRINT "L"
3460 VTAB 10: HTAB 464: PRINT "M"
3470 VTAB 10: HTAB 466: PRINT "N"
3480 VTAB 10: HTAB 468: PRINT "O"
3490 VTAB 10: HTAB 470: PRINT "P"
3500 VTAB 10: HTAB 472: PRINT "Q"
3510 VTAB 10: HTAB 474: PRINT "R"
3520 VTAB 10: HTAB 476: PRINT "S"
3530 VTAB 10: HTAB 478: PRINT "T"
3540 VTAB 10: HTAB 480: PRINT "U"
3550 VTAB 10: HTAB 482: PRINT "V"
3560 VTAB 10: HTAB 484: PRINT "W"
3570 VTAB 10: HTAB 486: PRINT "X"
3580 VTAB 10: HTAB 488: PRINT "Y"
3590 VTAB 10: HTAB 490: PRINT "Z"
3600 VTAB 10: HTAB 492: PRINT "A"
3610 VTAB 10: HTAB 494: PRINT "B"
3620 VTAB 10: HTAB 496: PRINT "C"
3630 VTAB 10: HTAB 498: PRINT "D"
3640 VTAB 10: HTAB 500: PRINT "E"
3650 VTAB 10: HTAB 502: PRINT "F"
3660 VTAB 10: HTAB 504: PRINT "G"
3670 VTAB 10: HTAB 506: PRINT "H"
3680 VTAB 10: HTAB 508: PRINT "I"
3690 VTAB 10: HTAB 510: PRINT "J"
3700 VTAB 10: HTAB 512: PRINT "K"
3710 VTAB 10: HTAB 514: PRINT "L"
3720 VTAB 10: HTAB 516: PRINT "M"
3730 VTAB 10: HTAB 518: PRINT "N"
3740 VTAB 10: HTAB 520: PRINT "O"
3750 VTAB 10: HTAB 522: PRINT "P"
3760 VTAB 10: HTAB 524: PRINT "Q"
3770 VTAB 10: HTAB 526: PRINT "R"
3780 VTAB 10: HTAB 528: PRINT "S"
3790 VTAB 10: HTAB 530: PRINT "T"
3800 VTAB 10: HTAB 532: PRINT "U"
3810 VTAB 10: HTAB 534: PRINT "V"
3820 VTAB 10: HTAB 536: PRINT "W"
3830 VTAB 10: HTAB 538: PRINT "X"
3840 VTAB 10: HTAB 540: PRINT "Y"
3850 VTAB 10: HTAB 542: PRINT "Z"
3860 VTAB 10: HTAB 544: PRINT "A"
3870 VTAB 10: HTAB 546: PRINT "B"
3880 VTAB 10: HTAB 548: PRINT "C"
3890 VTAB 10: HTAB 550: PRINT "D"
3900 VTAB 10: HTAB 552: PRINT "E"
3910 VTAB 10: HTAB 554: PRINT "F"
3920 VTAB 10: HTAB 556: PRINT "G"
3930 VTAB 10: HTAB 558: PRINT "H"
3940 VTAB 10: HTAB 560: PRINT "I"
3950 VTAB 10: HTAB 562: PRINT "J"
3960 VTAB 10: HTAB 564: PRINT "K"
3970 VTAB 10: HTAB 566: PRINT "L"
3980 VTAB 10: HTAB 568: PRINT "M"
3990 VTAB 10: HTAB 570: PRINT "N"
4000 VTAB 10: HTAB 572: PRINT "O"
4010 VTAB 10: HTAB 574: PRINT "P"
4020 VTAB 10: HTAB 576: PRINT "Q"
4030 VTAB 10: HTAB 578: PRINT "R"
4040 VTAB 10: HTAB 580: PRINT "S"
4050 VTAB 10: HTAB 582: PRINT "T"
4060 VTAB 10: HTAB 584: PRINT "U"
4070 VTAB 10: HTAB 586: PRINT "V"
4080 VTAB 10: HTAB 588: PRINT "W"
4090 VTAB 10: HTAB 590: PRINT "X"
4100 VTAB 10: HTAB 592: PRINT "Y"
4110 VTAB 10: HTAB 594: PRINT "Z"
4120 VTAB 10: HTAB 596: PRINT "A"
4130 VTAB 10: HTAB 598: PRINT "B"
4140 VTAB 10: HTAB 600: PRINT "C"
4150 VTAB 10: HTAB 602: PRINT "D"
4160 VTAB 10: HTAB 604: PRINT "E"
4170 VTAB 10: HTAB 606: PRINT "F"
4180 VTAB 10: HTAB 608: PRINT "G"
4190 VTAB 10: HTAB 610: PRINT "H"
4200 VTAB 10: HTAB 612: PRINT "I"
4210 VTAB 10: HTAB 614: PRINT "J"
4220 VTAB 10: HTAB 616: PRINT "K"
4230 VTAB 10: HTAB 618: PRINT "L"
4240 VTAB 10: HTAB 620: PRINT "M"
4250 VTAB 10: HTAB 622: PRINT "N"
4260 VTAB 10: HTAB 624: PRINT "O"
4270 VTAB 10: HTAB 626: PRINT "P"
4280 VTAB 10: HTAB 628: PRINT "Q"
4290 VTAB 10: HTAB 630: PRINT "R"
4300 VTAB 10: HTAB 632: PRINT "S"
4310 VTAB 10: HTAB 634: PRINT "T"
4320 VTAB 10: HTAB 636: PRINT "U"
4330 VTAB 10: HTAB 638: PRINT "V"
4340 VTAB 10: HTAB 640: PRINT "W"
4350 VTAB 10: HTAB 642: PRINT "X"
4360 VTAB 10: HTAB 644: PRINT "Y"
4370 VTAB 10: HTAB 646: PRINT "Z"
4380 VTAB 10: HTAB 648: PRINT "A"
4390 VTAB 10: HTAB 650: PRINT "B"
4400 VTAB 10: HTAB 652: PRINT "C"
4410 VTAB 10: HTAB 654: PRINT "D"
4420 VTAB 10: HTAB 656: PRINT "E"
4430 VTAB 10: HTAB 658: PRINT "F"
4440 VTAB 10: HTAB 660: PRINT "G"
4450 VTAB 10: HTAB 662: PRINT "H"
4460 VTAB 10: HTAB 664: PRINT "I"
4470 VTAB 10: HTAB 666: PRINT "J"
4480 VTAB 10: HTAB 668: PRINT "K"
4490 VTAB 10: HTAB 670: PRINT "L"
4500 VTAB 10: HTAB 672: PRINT "M"
4510 VTAB 10: HTAB 674: PRINT "N"
4520 VTAB 10: HTAB 676: PRINT "O"
4530 VTAB 10: HTAB 678: PRINT "P"
4540 VTAB 10: HTAB 680: PRINT "Q"
4550 VTAB 10: HTAB 682: PRINT "R"
4560 VTAB 10: HTAB 684: PRINT "S"
4570 VTAB 10: HTAB 686: PRINT "T"
4580 VTAB 10: HTAB 688: PRINT "U"
4590 VTAB 10: HTAB 690: PRINT "V"
4600 VTAB 10: HTAB 692: PRINT "W"
4610 VTAB 10: HTAB 694: PRINT "X"
4620 VTAB 10: HTAB 696: PRINT "Y"
4630 VTAB 10: HTAB 698: PRINT "Z"
4640 VTAB 10: HTAB 700: PRINT "A"
4650 VTAB 10: HTAB 702: PRINT "B"
4660 VTAB 10: HTAB 704: PRINT "C"
4670 VTAB 10: HTAB 706: PRINT "D"
4680 VTAB 10: HTAB 708: PRINT "E"
4690 VTAB 10: HTAB 710: PRINT "F"
4700 VTAB 10: HTAB 712: PRINT "G"
4710 VTAB 10: HTAB 714: PRINT "H"
4720 VTAB 10: HTAB 716: PRINT "I"
4730 VTAB 10: HTAB 718: PRINT "J"
4740 VTAB 10: HTAB 720: PRINT "K"
4750 VTAB 10: HTAB 722: PRINT "L"
4760 VTAB 10: HTAB 724: PRINT "M"
4770 VTAB 10: HTAB 726: PRINT "N"
4780 VTAB 10: HTAB 728: PRINT "O"
4790 VTAB 10: HTAB 730: PRINT "P"
4800 VTAB 10: HTAB 732: PRINT "Q"
4810 VTAB 10: HTAB 734: PRINT "R"
4820 VTAB 10: HTAB 736: PRINT "S"
4830 VTAB 10: HTAB 738: PRINT "T"
4840 VTAB 10: HTAB 740: PRINT "U"
4850 VTAB 10: HTAB 742: PRINT "V"
4860 VTAB 10: HTAB 744: PRINT "W"
4870 VTAB 10: HTAB 746: PRINT "X"
4880 VTAB 10: HTAB 748: PRINT "Y"
4890 VTAB 10: HTAB 750: PRINT "Z"
4900 VTAB 10: HTAB 752: PRINT "A"
4910 VTAB 10: HTAB 754: PRINT "B"
4920 VTAB 10: HTAB 756: PRINT "C"
4930 VTAB 10: HTAB 758: PRINT "D"
4940 VTAB 10: HTAB 760: PRINT "E"
4950 VTAB 10: HTAB 762: PRINT "F"
4960 VTAB 10: HTAB 764: PRINT "G"
4970 VTAB 10: HTAB 766: PRINT "H"
4980 VTAB 10: HTAB 768: PRINT "I"
4990 VTAB 10: HTAB 770: PRINT "J"
5000 VTAB 10: HTAB 772: PRINT "K"
5010 VTAB 10: HTAB 774: PRINT "L"
5020 VTAB 10: HTAB 776: PRINT "M"
5030 VTAB 10: HTAB 778: PRINT "N"
5040 VTAB 10: HTAB 780: PRINT "O"
5050 VTAB 10: HTAB 782: PRINT "P"
5060 VTAB 10: HTAB 784: PRINT "Q"
5070 VTAB 10: HTAB 786: PRINT "R"
5080 VTAB 10: HTAB 788: PRINT "S"
5090 VTAB 10: HTAB 790: PRINT "T"
5100 VTAB 10: HTAB 792: PRINT "U"
5110 VTAB 10: HTAB 794: PRINT "V"
5120 VTAB 10: HTAB 796: PRINT "W"
5130 VTAB 10: HTAB 798: PRINT "X"
5140 VTAB 10: HTAB 800: PRINT "Y"
5150 VTAB 10: HTAB 802: PRINT "Z"
5160 VTAB 10: HTAB 804: PRINT "A"
5170 VTAB 10: HTAB 806: PRINT "B"
5180 VTAB 10: HTAB 808: PRINT "C"
5190 VTAB 10: HTAB 810: PRINT "D"
5200 VTAB 10: HTAB 812: PRINT "E"
5210 VTAB 10: HTAB 814: PRINT "F"
5220 VTAB 10: HTAB 816: PRINT "G"
5230 VTAB 10: HTAB 818: PRINT "H"
5240 VTAB 10: HTAB 820: PRINT "I"
5250 VTAB 10: HTAB 822: PRINT "J"
5260 VTAB 10: HTAB 824: PRINT "K"
5270 VTAB 10: HTAB 826: PRINT "L"
5280 VTAB 10: HTAB 828: PRINT "M"
5290 VTAB 10: HTAB 830: PRINT "N"
5300 VTAB 10: HTAB 832: PRINT "O"
5310 VTAB 10: HTAB 834: PRINT "P"
5320 VTAB 10: HTAB 836: PRINT "Q"
5330 VTAB 10: HTAB 838: PRINT "R"
5340 VTAB 10: HTAB 840: PRINT "S"
5350 VTAB 10: HTAB 842: PRINT "T"
5360 VTAB 10: HTAB 844: PRINT "U"
5370 VTAB 10: HTAB 846: PRINT "V"
5380 VTAB 10: HTAB 848: PRINT "W"
5390 VTAB 10: HTAB 850: PRINT "X"
5400 VTAB 10: HTAB 852: PRINT "Y"
5410 VTAB 10: HTAB 854: PRINT "Z"
5420 VTAB 10: HTAB 856: PRINT "A"
5430 VTAB 10: HTAB 858: PRINT "B"
5440 VTAB 10: HTAB 860: PRINT "C"
5450 VTAB 10: HTAB 862: PRINT "D"
5460 VTAB 10: HTAB 864: PRINT "E"
5470 VTAB 10: HTAB 866: PRINT "F"
5480 VTAB 10: HTAB 868: PRINT "G"
5490 VTAB 10: HTAB 870: PRINT "H"
5500 VTAB 10: HTAB 872: PRINT "I"
5510 VTAB 10: HTAB 874: PRINT "J"
5520 VTAB 10: HTAB 876: PRINT "K"
5530 VTAB 10: HTAB 878: PRINT "L"
5540 VTAB 10: HTAB 880: PRINT "M"
5550 VTAB 10: HTAB 882: PRINT "N"
5560 VTAB 10: HTAB 884: PRINT "O"
5570 VTAB 10: HTAB 886: PRINT "P"
5580 VTAB 10: HTAB 888: PRINT "Q"
5590 VTAB 10: HTAB 890: PRINT "R"
5600 VTAB 10: HTAB 892: PRINT "S"
5610 VTAB 10: HTAB 894: PRINT "T"
5620 VTAB 10: HTAB 896: PRINT "U"
5630 VTAB 10: HTAB 898: PRINT "V"
5640 VTAB 10: HTAB 900: PRINT "W"
5650 VTAB 10: HTAB 902: PRINT "X"
5660 VTAB 10: HTAB 904: PRINT "Y"
5670 VTAB 10: HTAB 906: PRINT "Z"
5680 VTAB 10: HTAB 908: PRINT "A"
5690 VTAB 10: HTAB 910: PRINT "B"
5700 VTAB 10: HTAB 912: PRINT "C"
5710 VTAB 10: HTAB 914: PRINT "D"
5720 VTAB 10: HTAB 916: PRINT "E"
5730 VTAB 10: HTAB 918: PRINT "F"
5740 VTAB 10: HTAB 920: PRINT "G"
5750 VTAB 10: HTAB 922: PRINT "H"
5760 VTAB 10: HTAB 924: PRINT "I"
5770 VTAB 10: HTAB 926: PRINT "J"
5780 VTAB 10: HTAB 928: PRINT "K"
5790 VTAB 10: HTAB 930: PRINT "L"
5800 VTAB 10: HTAB 932: PRINT "M"
5810 VTAB 10: HTAB 934: PRINT "N"
5820 VTAB 10: HTAB 936: PRINT "O"
5830 VTAB 10: HTAB 938: PRINT "P"
5840 VTAB 10: HTAB 940: PRINT "Q"
5850 VTAB 10: HTAB 942: PRINT "R"
5860 VTAB 10: HTAB 944: PRINT "S"
5870 VTAB 10: HTAB 946: PRINT "T"
5880 VTAB 10: HTAB 948: PRINT "U"
5890 VTAB 10: HTAB 950: PRINT "V"
5900 VTAB 10: HTAB 952: PRINT "W"
5910 VTAB 10: HTAB 954: PRINT "X"
5920 VTAB 10: HTAB 956: PRINT "Y"
5930 VTAB 10: HTAB 958: PRINT "Z"
5940 VTAB 10: HTAB 960: PRINT "A"
5950 VTAB 10: HTAB 962: PRINT "B"
5960 VTAB 10: HTAB 964: PRINT "C"
5970 VTAB 10: HTAB 966: PRINT "D"
5980 VTAB 10: HTAB 968: PRINT "E"
5990 VTAB 10: HTAB 970: PRINT "F"
6000 VTAB 10: HTAB 972: PRINT "G"
6010 VTAB 10: HTAB 974: PRINT "H"
6020 VTAB 10: HTAB 976: PRINT "I"
6030 VTAB 10: HTAB 978: PRINT "J"
6040 VTAB 10: HTAB 980: PRINT "K"
6050 VTAB 10: HTAB 982: PRINT "L"
6060 VTAB 10: HTAB 984: PRINT "M"
6070 VTAB 10: HTAB 986: PRINT "N"
6080 VTAB 10: HTAB 988: PRINT "O"
6090 VTAB 10: HTAB 990: PRINT "P"
6100 VTAB 10: HTAB 992: PRINT "Q"
6110 VTAB 10: HTAB 994: PRINT "R"
6120 VTAB 10: HTAB 996: PRINT "S"
6130 VTAB 10: HTAB 998: PRINT "T"
6140 VTAB 10: HTAB 1000: PRINT "U"
6150 VTAB 10: HTAB 1002: PRINT "V"
6160 VTAB 10: HTAB 1004: PRINT "W"
6170 VTAB 10: HTAB 1006: PRINT "X"
6180 VTAB 10: HTAB 1008: PRINT "Y"
6190 VTAB 10: HTAB 1010: PRINT "Z"
6200 VTAB 10: HTAB 1012: PRINT "A"
6210 VTAB 10: HTAB 1014: PRINT "B"
6220 VTAB 10: HTAB 1016: PRINT "C"
6230 VTAB 10: HTAB 1018: PRINT "D"
6240 VTAB 10: HTAB 1020: PRINT "E"
6250 VTAB 10: HTAB 1022: PRINT "F"
6260 VTAB 10: HTAB 1024: PRINT "G"
6270 VTAB 10: HTAB 1026: PRINT "H"
6280 VTAB 10: HTAB 1028: PRINT "I"
6290 VTAB 10: HTAB 1030: PRINT "J"
6300 VTAB 10: HTAB 1032: PRINT "K"
6310 VTAB 10: HTAB 1034: PRINT "L"
6320 VTAB 10: HTAB 1036: PRINT "M"
6330 VTAB 10: HTAB 1038: PRINT "N"

```

```

1200 VTAB CC: HTAB 38: PRINT "128"
1210 VTAB 22: HTAB 17: PRINT "DIODE #:"
1220 VTAB 23: HTAB 17: PRINT "ARRAY #";I
1230 REM LABEL THE ABSCISSA
1240 HPLOT 23,3
1250 M = 128:N = 256:O = 768:S = 32
1260 T = 23:U = 155
1270 F = G + M * I:Q = P + O
1280 FOR KK = 1 TO M:R = M - KK:X = T + 2 * KK
1290 H1 = PEEK (P + R) + N * PEEK (Q + R)
1300 J1 = 4096:K1 = 65536: IF H1 > J1 THEN H1 = - (K1 - H1)
1310 H1 = H1 + OS
1320 HH = INT (H1 / S)
1330 Y = U - HH
1340 X = T + KK * 2
1350 ONERR GOTO 1500
1360 HPLOT TO X,Y: NEXT KK
1370 REM PLOT OUT THE DATA AS A GRAPH
1380 RETURN
1390 IF Z < 2 THEN 1430
1400 GOSUB 790
1410 GOSUB 920
1420 GOTO 400
1430 IF Z > 3 THEN 1460
1440 GOTO 90
1450 PRINT
1460 PRINT "PRESS RESET FOLLOWED BY RUN/DRS"
1470 PRINT
1480 PRINT "NOTE: IF A IS NOT IN POSITION IMMEDIATELY BY RUN/DRS AND CAN BE PROC
5555 THRO
1490 STOP

```

SEL6 allows data to be saved on a disk in drive #2. It saves both the data file and the gain and replicate data information as a second file on a single instruction. It suggests a simple coding system to help subsequent identification of the type of data being saved. Spaces and other delimiting characters should not be used in file names as they tend to get forgotten and the files have to be identified absolutely to read from them. Data for all 6 arrays are saved at once. A means file takes up a total of 10 sectors on the disk. The data file requires 13 sectors.

```

10 HIMEM: 29439
20 REM PROGRAM **SEL6**
30 HOME
40 VTAB 2: PRINT "THIS OPTION ALLOWS DATA TO BE SAVED ON A"
50 PRINT "A DISKETTE IN DRIVE #2": PRINT
60 PRINT "DATA IS SAVED IN A BINARY FILE.....": PRINT
70 PRINT ".....SUPPLEMENTARY INFORMATION LN": PRINT
80 PRINT "INTEGRATION TIMES, REPLICATIONS AND": PRINT
90 PRINT "A/DC SETTINGS IS ALSO SAVED AND": PRINT
100 PRINT "RELOADED WITH THE SAME COMMAND": PRINT : PRINT
110 PRINT "THE FILE NAME MUST CONTAIN INFORMATION": PRINT
120 PRINT "THAT DESCRIBES THE TYPE OF DATA SAVED":
130 VTAB 24: PRINT "(PRESS SPACE BAR TO CONTINUE)"
140 CALL - 756
150 HOME
160 PRINT "A FILE NAME MAY CONTAIN UP TO 30": PRINT
170 PRINT "CHARACTERS STARTING WITH A LETTER": PRINT
180 PRINT "THE FOLLOWING SIMPLE CODE IS SUGGESTED": PRINT
190 HTAB 4: PRINT "S.....SIGNAL DATA": PRINT
200 HTAB 4: PRINT "B.....BACKGROUND DATA": PRINT
210 HTAB 4: PRINT "D.....DIFFERENCE(SUBTRACTED VALUES)": PRINT
220 HTAB 4: PRINT "R.....RAW DATA": PRINT
230 HTAB 4: PRINT "M.....MEAN VALUES": PRINT
240 HTAB 4: PRINT "C.....CALIBRATION FILE": PRINT
250 PRINT "START A FILE NAME WITH CODE LETTERS": PRINT
260 PRINT "FOLLOWED BY A LABEL": PRINT
270 INPUT "ENTER FILE NAME";F$
280 G$ = F$ + ".Z"
290 REM FILE G$ HOLDS THE DATA COLLECTION PARAMETERS
300 HOME
310 VTAB 2: PRINT "ORIGIN OF DATA TO BE SAVED:-": PRINT
320 HTAB 4: PRINT "1. IN THE INPUT BUFFER": PRINT
330 HTAB 4: PRINT "2. BACKGROUND RAW DATA FILE": PRINT
340 HTAB 4: PRINT "3. ANALYTE DATA MEANS FILE": PRINT
350 HTAB 4: PRINT "4. BACKGROUND DATA MEANS FILE": PRINT
360 HTAB 4: PRINT "5. THE SET OF DATA THAT HAS JUST BEEN"
370 HTAB 7: PRINT "DISPLAYED ON THIS SCREEN OR ON AN": PRINT
380 HTAB 7: PRINT "OSCILLOSCOPE OR RECORDER": PRINT
390 PRINT
400 INPUT "ENTER 1,2,3,4 OR 5";S$
410 HOME
420 ON VAL (S$) GOTO 450,460,470,480,490
430 REM B=START OF DATA,C=START OF CODE FILE,L=LENGTH OF DATA FILE
440 REM CODE FILE IS ALWAYS 24 BYTES LONG
450 B = 32768:C = 32513:L = 2304: GOTO 490
460 B = 35072:C = 32550:L = 2304: GOTO 490
470 B = 30976:C = 32574:L = 1536: GOTO 490
480 B = 29110:C = 32598:L = 1536: GOTO 490
490 PRINT CHR$(4);"ESAVE";F$;"DZ,A";9;"L"
500 PRINT CHR$(4);"ESAVE";G$;"A";C;"L"
510 PRINT CHR$(4);"BLOADTES"

```

SEL7 displays the data stored in the input buffer on an oscilloscope, array by array. The oscilloscope should be switched to inverse polarity. The program requires that the digital to analog converter located in the start pulse indicator box be powered. The DAC is wired four bits higher on the interface board than the data in the buffer. Consequently MC12.OBJ0 is used to move all the data in the buffer 4 bits higher at the start of the display and MC12B.OBJ0 moves the data 4 bits lower at the end.

Program MC12A.OBJ0 is the display program. It uses a software generated strobe to enable the latches feeding data to the DAC and generates a trigger for the oscilloscope by means of two successive software operations. The strobe and trigger come from the Apple through the game I/O connector.

```

10 HIMEM: 29439
20 REM PROGRAM **SEL7**
30 HOME
40 PRINT "THIS OPTION DISPLAYS THE DATA STORED IN": PRINT
50 PRINT "THE INPUT BUFFER ON AN OSCILLOSCOPE": PRINT
60 PRINT "THE ARRAYS ARE DISPLAYED SINGLY": PRINT
70 PRINT "*****"
80 PRINT CHR$(4);"BRUNMC12.OBJ0,D1"
90 REM SHIFT DATA IN THE BUFFER 4 BITS HIGHER
100 PRINT
110 PRINT "THE DISPLAY FOR EACH ARRAY WILL CONTINUE": PRINT
120 PRINT "UNTIL ANY KEY IS DEPRESSED": PRINT
130 INPUT "ENTER ARRAY # (IF >5 IT RETURNS TO MAIN MENU)":I
140 REM CONNECT DAC LINES TO ALL FB OUTPUTS AND UFFER 4 PA OUTPUTS
150 IF I > 5 THEN 280
160 HOME
170 INVERSE : PRINT "TURN ON THE DZAC POWER SUPPLY BY PUTTING THE SWITCH AT THE
BACK OF THE GREY BOX IN THE UP POSITION": PRINT
180 PRINT "PUT SELECT SWITCH IN SCOPE POSITION": PRINT
190 NORMAL
200 PRINT
210 A = 32768:B = 768:C = 128:D = A + I * C:E = D + B:F = 256
220 DH = INT (D / F):DL = D - DH * F:EH = INT (E / F):EL = E - EH * F
230 POKE 32622,DL: POKE 32623,DH: POKE 32624,EL: POKE 32625,EH
240 REM THE START ADDRESSES FOR THE DATA TO BE DISPLAYED
250 PRINT CHR$(4);"BRUNMC12A.OBJ0"
260 REM RUN THE DISPLAY PROGRAM
270 GOTO 100
280 PRINT CHR$(4);"BRUNMC12E.OBJ0"
290 REM SHIFT DATA IN THE BUFFER 4 BITS LOWER
300 PRINT CHR$(4);"RUNDRS"

```

```

SOURCE FILE: MC12
----- NEXT OBJECT FILE NAME IS MC12.OBJ0
9200:          1          ORG  $9200
9200:          2 *PROGRAM TO SHIFT 12 BITS OF DATA 4 BITS HIGHER
9200:A2 00      3          LDX  #$00
9202:A0 04      4 BR1     LDY  #$04          ;LOAD THE NUMBER OF SHIFTS TO BE MADE
9204:1E 00 80   5 BR2     ASL  $8000,X      ;SHIFT LOW BYTE ONE BIT
9207:          6 *TO THE LEFT AND PUT THE MSB INTO THE CARRY FLAG
9207:3E 00 83   7          ROL  $8300,X      ;SHIFT THE HIGH BYTE ONE BIT
920A:          8 *TO THE LEFT AND PICK UP THE CARRY INTO THE LSB
920A:1E 00 81   9          ASL  $8100,X
920D:3E 00 84  10         ROL  $8400,X
9210:1E 00 82  11         ASL  $8200,X
9213:3E 00 85  12         ROL  $8500,X
9216:88        13         DEY          ;DECREMENT THE SHIFT COUNTER
9217:D0 EB     14         ENB BR2      ;SHIFT AGAIN IF NECESSARY
9219:CA        15         DEX          ;CHANGE TO THREE NEW DATA POINTS
921A:D0 E4     16         ENB BR1
921C:60        17         RTS          ;BACK TO BASIC

```

SOURCE FILE: MC12A

```

----- NEXT OBJECT FILE NAME IS MC12A.OBJ0
9200:          1      ORG      $9200
9200:          2 *OUTPUT TO OSCILLOSCOPE
9200:          3 *ENTER STARTING ADDRESSES FOR DATA FOR INDIVIDUAL ARRAYS
C400:          4 PORT    EQU    $C400    ;LABEL THE INPUT OUTPUT SLOT
9200:AD 6E 7F  5      LDA    $7F6E    ;LOAD THE LOW BYTE OF THE
9203:          6 *ADDRESS OF THE LOW BYTE BASE ADDRESS FOR THE ARRAY DATA
9203:BD 29 92  7      STA    ADD1+1    ;WRITE IT FORWARD IN THE PROGRAM
9206:AD 6F 7F  8      LDA    $7F6F    ;LOAD THE HIGH BYTE OF THE
9209:          9 *ADDRESS OF THE LOW BYTE BASE ADDRESS FOR THE ARRAY DATA
9209:BD 2A 92 10     STA    ADD1+2    ;WRITE IT FORWARD IN THE PROGRAM
920C:AD 70 7F 11     LDA    $7F70    ;LOAD THE LOW BYTE OF THE
920F:          12 *ADDRESS OF THE HIGH BYTE BASE ADDRESS FOR THE ARRAY DATA
920F:BD 2F 92 13     STA    ADD2+1    ;WRITE IT FORWARD IN THE PROGRAM
9212:AD 71 7F 14     LDA    $7F71    ;LOAD THE HIGH BYTE OF THE
9215:          15 *ADDRESS OF THE HIGH BYTE BASE ADDRESS FOR THE ARRAY DATA
9215:BD 30 92 16     STA    ADD2+2    ;WRITE IT FORWARD IN THE PROGRAM
9218:          17 *TRIGGER THE SCOPE WITH A SOFTWARE GENERATED STROBE
9218:AD 5E C0 18     BR2    LDA    $C05E
921B:AD 5A 00 19     LDA    $C05A
921E:          20 *SET DDRAS FOR ALL OUTPUTS
921E:A9 FF 21      LDA    $FF
9220:BD 12 C4 22     STA    PORT+$12
9223:BD 13 C4 23     STA    PORT+$13
9226:A2 7F 24      LDX    $7F    ;SET UP FOR 128 DIODES
9228:          25 *READ AND THEN OUTPUT LOW AND HIGH BYTES
9228:BD AA AA 26     ADD1   LDA    $AAAA,X
922E:BD 11 C4 27     STA    PORT+$11
922E:BD AA AA 28     ADD2   LDA    $AAAA,X
9231:BD 10 C4 29     STA    PORT+$10
9234:AD 40 C0 30     LDA    $C040    ;NEGATIVE STROBE TO ENABLE THE LATCHES
9237:CA 31      DEX
9238:10 EE 32     BPL    ADD1
923A:          33 *LOOK FOR KEYBOARD INPUT TO END CYCLING
923A:AD 00 C0 34     LDA    $C000
923D:30 03 35     BMI    BR3
923F:4C 18 92 36     JMP    BR2    ;TRIGGER AGAIN
9242:AD 10 C0 37     BR3    LDA    $C010
9245:          38 *BACK TO BASIC PROGRAM
9245:60 39     RTS

```

SOURCE FILE: MC12B

```

----- NEXT OBJECT FILE NAME IS MC12B.OBJ0
9200:          1      ORG      $9200
9200:          2 *PROGRAM TO SHIFT 12 BIT VALUES 4 BITS LOWER (REVERSE OF MC12
)
9200:A2 00 3      LDX    $00
9202:A0 04 4     BR1    LDY    $04    ;LOAD THE NUMBER OF SHIFTS TO BE MADE
9204:5E 00 83 5     BR2    LSR    $8300,X    ;SHIFT HIGH BYTE ONE BIT
9207:          6 *TO THE RIGHT AND PUT THE LSB INTO THE CARRY FLAG
9207:7E 00 80 7     ROR    $8000,X    ;SHIFT LOW BYTE ONE BIT
920A:          8 *TO THE RIGHT AND PICK UP THE CARRY INTO THE MSB
920A:5E 00 84 9     LSR    $8400,X
920D:7E 00 81 10    ROR    $8100,X
9210:5E 00 85 11    LSR    $8500,X
9213:7E 00 82 12    ROR    $8200,X
9216:8B 13     DEY    ;DECREMENT THE SHIFT COUNTER
9217:D0 EB 14     BNE    BR2    ;SHIFT AGAIN IF NECESSARY
9219:CA 15     DEX    ;CHANGE TO THREE NEW DATA POINTS
921A:D0 E6 16     BNE    BR1
921C:60 17     RTS    ;BACK TO BASIC

```

SEL8 is similar to SEL7 except that the output rate of the data values is slowed down to suit the response speed of a chart recorder. The data output rate can be altered by the user. If the buffer values are the result of a subtraction, there will be some values below zero because of noise. These values appear in the data as having high values in the most significant nibble of the high byte. This makes a mess of the output.

MC21.OBJ0 allows the addition of an offset value to bring all data values positive first.

MC13.OBJ0 is the display program incorporating nested loops to slow down the output rate.

```

10 HIMEM: 29439
20 REM PROGRAM **SELB**
30 HOME
40 PRINT "THIS OPTION DISPLAYS THE DATA STORED IN": PRINT
50 PRINT "THE INPUT BUFFER ON A CHART RECORDER": PRINT
60 PRINT "THE ARRAYS ARE DISPLAYED SINGLY": PRINT
70 PRINT "*****"
80 PRINT : PRINT "ENTER RECORDER RESPONSE SPEED"
90 PRINT : PRINT "IN POINTS PER MINUTE": PRINT : PRINT "MINIMUM 40": INPUT L
100 IF L < 40 GOTO 90
110 POKE 32627, INT (9710 / L)
120 REM POKES THE VALUE FOR THE INNER LOOP COUNTER INTO
130 REM SCRATCHPAD MEMORY
140 PRINT "IF BUFFER IS LOADED ENTER 1"
150 PRINT : PRINT "IF DATA IS ON DISKETTE ENTER 2"
160 INPUT A$
170 ON VAL (A$) GOTO 240,190
180 REM LOAD THE BUFFER FROM A DISK
190 INPUT "ENTER FILE NAME";F$
200 G$ = F$ + ".Z"
210 PRINT CHR$ (4);"ELOAD";F$;","D2,A$8000"
220 PRINT CHR$ (4);"ELOAD";G$;","A$7F01"
230 PRINT CHR$ (4);"ELOADTEST,D1"
240 PRINT : PRINT "IF DATA IS THE RESULT OF A "
250 PRINT "SUBTRACTION ENTER 1"
260 PRINT : PRINT "IF NOT THEN ENTER 2"
270 PRINT : INPUT B$
280 ON VAL (B$) GOTO 330,370
290 PRINT
300 REM IF A SUBTRACTION WAS USED NOISE WILL CAUSE SOME NEGATIVE
310 REM VALUES TO BE IN THE BUFFER AND THIS CAUSES A DISASTER
320 REM TO PREVENT THIS ADD AN OFFSET VALUE TO THE BUFFER DATA
330 PRINT "ENTER OFF SET 1 TO 255 "
340 INPUT H
350 POKE 32628,H
360 PRINT CHR$ (4);"BRUNMC21.OBJ0"
370 PRINT CHR$ (4);"BRUNMC12.OBJ0"
380 REM SHIFT DATA IN THE BUFFER 4 BITS HIGHER
390 INPUT "ENTER ARRAY # (IF >5 IT RETURNS TO MAIN MENU)";I
400 IF I > 5 THEN 530
410 HOME
420 INVERSE : PRINT "TURN ON THE D/AC POWER SUPPLY BY PUTTING THE SWITCH AT THE
BACK OF THE GREY BOX IN THE UP POSITION": PRINT
430 PRINT "PUT SELECT SWITCH IN RECORDER POSITION": PRINT
440 PRINT "PRESS SPACE BAR TO START": NORMAL
450 CALL - 756
460 A = 32768:E = 768:C = 128:D = A + I * C:E = D + B:F = 256
470 DH = INT (D / F):DL = D - DH * F:EH = INT (E / F):EL = E - EH * F
480 POKE 32622,DL: POKE 32623,DH: POKE 32624,EL: POKE 32625,EH
490 PRINT
500 PRINT CHR$ (4);"BRUNMC13.OBJ0"
510 REM OUTPUT THE DATA TO THE RECORDER
520 GOTO 390
530 PRINT CHR$ (4);"BRUNMC12E.OBJ0"
540 REM SHIFT DATA IN THE BUFFER 4 BITS LOWER
550 PRINT CHR$ (4);"RUNDRS"

```

SOURCE FILE: MC21

----- NEXT OBJECT FILE NAME IS MC21.OBJO

```

9200:          1      ORG      $9200
9200:          2 *PROGRAM TO ADD AN OFFSET VALUE TO THE INPUT BUFFER DATA
9200:          3 *VALUES PRIOR TO PLOTTING ON A CHART RECORDER. BASIC
9200:          4 *PROGRAM HAS PREVIOUSLY POKED THE OFFSET VALUE INTO
9200:          5 *ADDRESS $7F74 (32628)
9200:A2 00      6      LDX      $000      ;ZERO COUNTER
9202:18      7 BR1      CLC          ;CLEAR CARRY FLAG
9203:BD 00 80   8      LDA      $8000,X   ;LOAD DATA LOW BYTE
9206:6D 74 7F   9      ADC      $7F74     ;ADD THE OFFSET
9209:9D 00 80  10     STA      $8000,X   ;STORE THE SUM
920C:ED 00 83  11     LDA      $8300,X   ;LOAD DATA HIGH BYTE
920F:69 00     12     ADC      $000      ;ADD THE VALUE OF THE CARRY FLAG
9211:9D 00 83  13     STA      $8300,X   ;STORE AGAIN
9214:18      14     CLC
9215:ED 00 81  15     LDA      $8100,X
9218:6D 74 7F  16     ADC      $7F74
921E:9D 00 81  17     STA      $8100,X
921E:ED 00 84  18     LDA      $8400,X
9221:69 00     19     ADC      $000
9223:9D 00 84  20     STA      $8400,X
9226:18      21     CLC
9227:ED 00 82  22     LDA      $8200,X
922A:6D 74 7F  23     ADC      $7F74
922D:9D 00 82  24     STA      $8200,X
9230:ED 00 85  25     LDA      $8500,X
9233:69 00     26     ADC      $000
9235:9D 00 85  27     STA      $8500,X
9238:CA      28     DEX          ;DECREMENT COUNTER
9239:1D 00 C7  29     BNE      BR1      ;GO ROUND AGAIN IF NOT FINISHED
923E:60      30     RTS          ;RETURN TO BASIC

```

SOURCE FILE: MC13

```

----- NEXT OBJECT FILE NAME IS MC13.OBJO
9200:          1      ORG  $9200
9200:          2 *OUT PUT TO CHART RECORDER
9200:          3 *ENTER STARTING ADDRESSES FOR DATA FOR INDIVIDUAL ARRAYS
C400:          4 PORT EQU  $C400      ;LABEL THE INPUT/OUTPUT SLOT
9200:AD 6E 7F  5      LDA  $7F6E      ;LOAD THE LOW BYTE OF THE
9203:          6 *ADDRESS OF THE LOW BYTE BASE ADDRESS FOR THE ARRAY DATA
9203:BD 23 92  7      STA  ADD1+1    ;WRITE IT FORWARD IN THE PROGRAM
9206:AD 6F 7F  8      LDA  $7F6F      ;LOAD THE HIGH BYTE OF THE
9209:          9 *ADDRESS OF THE LOW BYTE BASE ADDRESS FOR THE ARRAY DATA
9209:BD 24 92 10     STA  ADD1+2    ;WRITE IT AHEAD IN THE PROGRAM
920C:AD 70 7F 11     LDA  $7F70      ;LOAD THE LOW BYTE OF THE
920F:          12 *ADDRESS OF THE HIGH BYTE BASE ADDRESS FOR THE ARRAY DATA
920F:BD 29 92 13     STA  ADD2+1    ;WRITE IT FORWARD IN THE PROGRAM
9212:AD 71 7F 14     LDA  $7F71      ;LOAD THE HIGH BYTE OF THE
9215:          15 *ADDRESS OF THE HIGH BYTE BASE ADDRESS FOR THE ARRAY DATA
9215:BD 2A 92 16     STA  ADD2+2    ;WRITE IT FORWARD IN THE PROGRAM
9218:A9 FF      17     LDA  $FF
921A:BD 12 C4 18     STA  PORT+$12
921D:BD 13 C4 19     STA  PORT+$13
9220:A2 7F      20     LDX  $7F          ;SET UP FOR 128 DIODES
9222:          21 *READ AND THEN OUTPUT LOW AND HIGH BYTES
9222:BD AA AA  22     ADD1  LDA  $AAAA,X
9225:BD 11 C4  23     STA  PORT+$11
9228:BD AA AA  24     ADD2  LDA  $AAAA,X
922E:BD 10 C4  25     STA  PORT+$10
922E:AD 40 C0  26     LDA  $C040      ;NEGATIVE STROBE TO ENABLE THE LATCHES
9231:          27 *ENTER DELAY LOOP TO SUIT THE "SLOW RESPONSE OF THE RECORDER"
9231:          28 *LOAD THE NUMBER OF CYCLES IN THE INNER LOOP
9231:A9 00      29     LDA  $00
9233:BD 72 7F  30     STA  $7F72
9236:A0 00      31     LDY  $00          ;ZERO THE INNER LOOP CYCLE COUNTER
9238:18        32     BR4   CLC          ;ENTER THE OUTER LOOP
9239:A9 00      33     LDA  $00
923E:18        34     BR5   CLC          ;ENTER THE INNER LOOP
923E:69 01      35     ADC  $01
923E:48        36     FPA          ;WASTE SOME TIME
923F:68        37     PLA
9240:48        38     FPA
9241:68        39     PLA
9242:CD 72 7F  40     CMP  $7F72
9245:D0 F4      41     BNE  BR5          ;END OF INNER LOOP CYCLE
9247:CB        42     INY          ;COUNT THE INNER LOOP CYCLE
9248:CC 73 7F  43     CPY  $7F73      ;COMPARE TO THE REQUIRED NUMBER
924E:D0 EB      44     BNE  BR4          ;COMPLETE DELAY CYCLE
924D:CA        45     DEX
924E:10 D2      46     BFL  ADD1      ;FETCH ANOTHER DATA POINT
9250:60        47     RTS          ;BACK TO FASTC

```

SEL9 lists the data values array by array and allows them to be printed out. All values are given in voltages.

SEL10 pair averages the input buffer turning 128 data points into 127 two point averages. The program is useful to reduce the odd-even pattern before displaying the data values.

MC20.OBJ0 carries out the averaging in machine code. The effect is shown in Figure 59.

SEL11 calculates the peak height against a selected background calculated from off-peak diodes. The background selection used depends upon the quality of the observed background. It calculates standard deviations of the background and the signal to noise ratio based on the background variability. It also calculates the peak height in terms of volts per second of integration time. The program will hang if a single off-peak diode is used as a background value.

SEL12 calculates concentrations from peak heights using data obtained from calibration standards. Concentrations are calculated by linear interpolation (or extrapolation) from two calibration standards, one of which may be zero.

```

10 HIMEM: 29439
20 REM PROGRAM **SEL9**
30 REM THIS OPTION LISTS THE DIODE DATA VALUES FOR A SINGLE ARRAY.
40 REM IT ALSO ALLOWS A PRINTOUT OF THE VALUES
50 HOME
60 PRINT "THIS OPTION DISPLAYS VALUES AS VOLTAGES"
70 PRINT
80 PRINT
90 PRINT "DATA CAN BE:-
100 PRINT "1. SINGLE RUN IN THE INPUT BUFFER"
110 PRINT
120 PRINT
130 PRINT "2. SINGLE RUN IN THE BACKGROUND DATA"
140 HTAB 4: PRINT "FILE"
150 PRINT
160 PRINT "3. SUBTRACTED MEAN VALUES STORED"
170 HTAB 4: PRINT "IN THE INPUT BUFFER"
180 PRINT
190 PRINT "4. ANALYTE SIGNAL MEANS"
200 PRINT
210 PRINT "5. BACKGROUND MEAN VALUES"
220 PRINT
230 PRINT "6. FROM A DISKETTE IN DRIVE #2"
240 PRINT
250 INPUT "ENTER 1,2,3,4,5 OR 6 ";E$
260 ON VAL (E$) GOTO 280,290,300,310,320,330
270 REM F=BASE ADDRESS FOR THE GAIN CODES AND C=BASE ADDRESS FOR THE DATA
280 F = 32525:G = 32768: GOTO 400
290 F = 32562:G = 35072: GOTO 400
300 F = 32525:G = 32768: GOTO 400
310 F = 32586:G = 30976: GOTO 400
320 F = 32610:G = 29440: GOTO 400
330 INPUT "ENTER FILE NAME ";F$
340 REM LOAD FROM DISKETTE TO INPUT BUFFER
350 G$ = F$ + "Z"
360 PRINT CHR$(4);"ELOAD";F$;" ,D2,A$8000"
370 PRINT CHR$(4);"ELOAD";G$;" ,A$7F01"
380 PRINT CHR$(4);"ELOADTEST,D1"
390 F = 32525:G = 32768
400 H = 16:F = 4096:D = 256:E = 768:M = 1:R = 128
410 INPUT "ENTER ARRAY # ";I
420 J = PEEK (F + I):K = INT (J / H): REM RETAIN UPPER 4 BITS ONLY
430 L = K - INT (K / 4) * 4
440 IF L = 0 THEN B = 5
450 IF L = 1 THEN B = 1
460 IF L = 2 THEN B = 0.5
470 IF L = 3 THEN B = 0.1
480 C = 0: IF K > 3 THEN C = - B
490 D = (B - C) / F: REM VALUE OF I.S.E
500 PRINT "CHOOSE"
510 HTAB 4: PRINT "1. SELECT A GROUP OF DIODES (MAX "3")" PRINT
520 HTAB 4: PRINT "2. DISPLAY ALL DIODES.USE CONTROL "3" PRINT
530 HTAB 7: PRINT "TO STOP DISPLAY TO READ : PRINT
540 INPUT "SELECT 1 OR 2 ";A$
550 ON VAL (A$) GOTO 560,610
560 PRINT : INPUT "ENTER # OF FIRST DIODE ";W
570 PRINT : INPUT "ENTER # OF LAST DIODE ";X
580 IF V = W + 1 THEN PRINT : GOTO 590
590 GOSUB 630
600 GOTO 560

```

```
610 W = 1:V = 128: GOSUB 630
620 GOTO 740
630 PRINT "ARRAY # ";I
640 FOR J = W TO V
650 U = R - J:N = G + I * R:D = N + E
660 S = PEEK(N + U) + D * PEEK(O + U)
670 IF S > P - M THEN S = S - D * D
680 REM CORRECT FOR VALUES BELOW ZERO
690 T = S * Q + C:T = INT (T * 10 ^ 5 + .5) / INT (10 ^ 5)
700 REM CALCULATE THE VOLTAGE AND ROUND OFF TO 5 DECIMAL PLACES
710 PRINT "# ";J;" ";T;"VOLTS"
720 NEXT J
730 RETURN
740 CALL - 756: HOME
750 PRINT "SELECT:-": PRINT
760 HTAB 4: PRINT "1. RETURN TO MAIN MENU": PRINT
770 HTAB 4: PRINT "2. ANOTHER ARRAY ": PRINT
780 HTAB 4: PRINT "3. ANOTHER FILE ": PRINT
790 HTAB 4: PRINT "4. MAKE A PRINTED COPY": PRINT
800 INPUT "ENTER 1,2,3 OR 4 ";B$
810 ON VAL (B$) GOTO 820,410,90,830
820 PRINT CHR$(4);"RUNDRS"
830 PRINT CHR$(4);"PR#1": GOSUB 630
840 PRINT CHR$(4);"PR#0": GOTO 740
```



```

10 HIMEM: 29439: HOME
20 REM PROGRAM **SEL11**
30 REM CALCULATE PEAK HEIGHT AGAINST SELECTED BACKGROUND VALUES
40 DIM V1(12),B1(12)
50 GOTO 190
60 REM DECODE THE INTEGRATION TIME
70 H = PEEK (F + I + I) + D * PEEK (F + I + I + C):K = H * P
80 REM DECODE THE GAIN CODE
90 J = INT (( PEEK (F + L + J) ) / E)
100 N = J - INT (J / M) * M
110 IF N = 0 THEN Q = 5
120 IF N = 1 THEN Q = 1
130 IF N = 2 THEN Q = 0.5
140 IF N = 3 THEN Q = 0.1
150 Q = 0: IF J > 3 THEN Q = 0
160 R = (Q - Q) / 9
170 REM THE VALUE OF THE LSB
180 RETURN
190 F = 768:C = 1:D = 256:E = 16:L = 12:M = 4:P = 3.1289E - 3:S = D * E:T = 128:
T1 = 4095
200 PRINT "THIS OPTION OBTAINS A DATA VALUE": PRINT
210 PRINT "FROM A FILE BY SUBTRACTING BACKGROUND": PRINT
220 PRINT "VALUES FROM THE SAME FILE": PRINT
230 PRINT "THE DATA FILE CAN BE": PRINT
240 PRINT "1. IN THE INPUT BUFFER AS A SINGLE RUN"
250 PRINT "OR AS MEANS"
260 PRINT "2. IN THE ANALYTE MEANS FILE": PRINT
270 PRINT "3. ON A DISKETTE IN DRIVE # 2"
280 INPUT "ENTER 1,2 OR 3 ";B#
290 REM LOCATE THE DATA FILE
300 ON VAL (B#) GOTO 390,310,330
310 F = 32574:G = 30976: GOTO 400
320 REM LOAD FILE FROM DISKETTE
330 INPUT "ENTER FILE NAME ";F#
340 G# = F# + "Z"
350 PRINT CHR# (4);"ELOAD";F#;" ,D2,A#8000"
360 PRINT CHR# (4);"ELOAD";G#;" ,A#7F01"
370 PRINT CHR# (4);"ELOADTEST,D1"
380 N1 = 8
390 F = 32513:G = 32768
400 PRINT
410 PRINT : PRINT : PRINT "-----"
420 PRINT "THE METHOD DEPENDS ON THE BACKGROUND"
430 PRINT : PRINT "1. WHERE THE BACKGROUND LEVEL IS FLAT": PRINT
440 PRINT "2. WHERE THE BACKGROUND IS FLAT "
450 HTAB 5: PRINT "BUT ODD EVEN PATTERN IS SECTOR"
460 PRINT "3. WHERE A SPECIAL BACKGROUND "
470 HTAB 5: PRINT "IS TO BE USED"
480 PRINT
490 INPUT "ENTER CORRESPONDING NUMBER ";A#
500 REM SELECT THE TYPE OF BACKGROUND AVAILABLE
510 INPUT "ENTER ARRAY # 0 TO 5 ";I
520 F2 = G + I * Y:P3 = E2 + B
530 PRINT : IF I > 5 GOTO 510
540 INPUT "ENTER CODE #OF PEAK 1 TO 128 ";A
550 GOSUB 40
560 U = I - A:V = PEEK (G + I * I + U) + D * PEEK (G + B + I * J + U)
570 IF U > 11 THEN V = V - D * D
580 ON VAL (A) GOTO 590,650,710
590 I(1) = A : I(2) = A - 1:I(3) = A - 2:I(4) = A - 3:I(5) = A - 4
600 I(6) = A - 5:I(7) = A - 6:I(8) = A - 7:I(9) = A - 8
610 I(10) = A - 9:I(11) = A - 10:I(12) = A - 11

```

```

610 N1 = 8
620 GOSUB 950
630 GOSUB 830
640 GOTO 1040
650 B1(0) = A - 14:B1(1) = A - 12:B1(2) = A - 10:B1(3) = A - 8
660 B1(4) = A + 8:B1(5) = A + 10:B1(6) = A + 12:B1(7) = A + 14
670 N1 = 8
680 GOSUB 950
690 GOSUB 830
700 GOTO 1040
710 PRINT "ENTER DIODE #'S OF BACKGROUND"
720 PRINT "UP TO 12 NUMBERS EACH ONE FOLLOWED BY A RETURN"
730 PRINT "AFTER LAST DIODE NUMBER ENTER 'END'"
740 INVERSE : PRINT "PROGRAM NEEDS AT LEAST 2 VALUES": NORMAL
750 REM IF ONLY ONE VALUE USED THE PROGRAM WILL HANG
760 K1 = 0
770 INPUT A$: IF A$ = "END" THEN GOTO 790
780 B1(K1) = VAL (A$):K1 = K1 + 1: GOTO 770
790 N1 = K1
800 GOSUB 950
810 GOSUB 830
820 GOTO 1040
830 REM SUBROUTINE TO CALCULATE MEAN AND SD
840 REM VALUES IN V1(12)
850 REM NO. OF VALUES IN N1
860 REM RETURNS MEAN IN M1 AND SD IN S1
870 I1 = 0:J1 = 0
880 FOR L1 = 0 TO N1 - 1
890 I1 = I1 + V1(L1)
900 J1 = J1 + (V1(L1)) ^ 2
910 NEXT L1
920 M1 = I1 / N1
930 S1 = SQR ((J1 - (I1 ^ 2) / N1) / (N1 - 1))
940 RETURN
950 REM SUBROUTINE TO PUT BACKGROUND DIODE VALUES INTO V1(12)
960 REM NUMBER OF VALUES IS IN N1
970 REM POSITIONS OF BACKGROUND RELATIVE TO PEAK IS IN B1(12)
980 REM RETURNS BACKGROUND DIODE VALUES IN V(12)
990 FOR K1 = 0 TO N1 - 1
1000 V1 = T - B1(K1):V1(K1) = FEEL (B2 + (V1) + D * (T - V1))
1010 IF V1(K1) > T1 THEN V1(K1) = T1
1020 NEXT K1
1030 RETURN
1040 INPUT "ENTER TITLE":C$
1050 PRINT CHR$(4):PR#1
1060 PRINT C$
1070 PRINT F$
1080 PRINT " ARRAY # ";I
1090 PRINT " DIODE # ";A
1100 PRINT " BACKGROUND METHOD ";A$
1110 REM VALUES ROUNDED OUT TO 5 DECIMAL PLACES
1120 PRINT " PEAK HT. "; INT ((V - M1) * R * 10 ^ 5 + .5) / (10 ^ 5)
1130 PRINT "INTEGRATION" TIME = ";V;" SECONDS"
1140 PRINT "BACKGROUND MEAN "; INT ((M1 * R + 2) * 10 ^ 5 + .5) / (10 ^ 5)
1150 PRINT " STANDARD DEVIATION OF BACKGROUND "; INT ((S1 * R) * 10 ^ 5 + .5) / (10 ^ 5)
1160 PRINT " S/NR "; INT ((V - M1) / S1) * 10 ^ 5 + .5) / (10 ^ 5)
1170 PRINT " "; INT ((D * (T - M1)) * 10 ^ 5 + .5) / (10 ^ 5)
1180 PRINT : PRINT
1190 PRINT CHR$(1):PR#0
1200 GOTO 70

```

```

10 HIMEM: 29439: HOME
20 REM PROGRAM **SEL12**
30 REM CALCULATE CONCENTRATIONS FROM PEAK HEIGHTS AND
40 REM CALIBRATION VALUES
50 PRINT "THIS OPTION CALCULATES SOLUTION "
60 PRINT : PRINT "CONCENTRATIONS FROM VOLTAGE": PRINT
70 PRINT "OUTPUTS BY LINEAR INTERPOLATION"
80 N = 1: PRINT
90 INPUT "ENTER ELEMENT NAME. IF DONE ENTER DONE ";A$(N)
100 IF A$(N) = "DONE" GOTO 200
110 INPUT "ENTER HIGH STD CONC IN PPM ";X
120 X(N) = X
130 INPUT "ENTER HIGH READING IN VOLTS ";R
140 R(N) = R
150 INPUT "ENTER LOW STD CONC IN PPM ";T$
160 REM IF NO ENTRY IS MADE FOR A LOW STD ZERO IS ASSUMED
170 T(N) = VAL (T$)
180 INPUT "ENTER LOW READING IN VOLTS ";Z$
190 Z(N) = VAL (Z$):N = N + 1: GOTO 90
200 G = N - 1: FOR N = 1 TO G: PRINT N;" ";A$(N): PRINT : NEXT N
210 INPUT "ENTER SOLUTION NAME ";B$
220 PRINT CHR$ (4);"PR#1": PRINT B$:
230 PRINT CHR$ (4);"PR#0"
240 INPUT "ENTER ELEMENT # ";N
250 INPUT "ENTER READING IN VOLTS ";Q(N)
260 Q = Q(N):R = R(N):T = T(N):X = X(N):Z = Z(N)
270 M(N) = ((X - T) * Q + R * T - Z * X) / (R - Z)
280 REM CALCULATE THE CONCENTRATION
290 PRINT CHR$ (4);"PR#1"
300 PRINT A$(N);" CONC = ";M(N);" PPM"
310 PRINT CHR$ (4);"PR#0"
320 GOTO 240

```

ARRAYSET is a BASIC program that produces a list of the useful lines for the elements to be considered in first, second and third order. The program lists them in spectral order over the range governed by the physical size and shape of the direct reader. The original source of the data is the tables published by Winge, Peterson and Fassel [43]. These have been entered on a disk as a series of text files by use of the program ELEMENTINPUT. The text files are labelled by the atomic symbol of the element and the number of lines (of all 3 orders) listed. Lines not listed in the Winge tables are not included.

The ARRAYSET program combines the text files into a dimensional array within a single text file and then order sorts them using QUICKSORTHIGH, a version of a fast machine code sorting program developed by Bongers [50].

The output for each line gives the order in sequence, the spectral position, the element and the symbol for ion or atomic line, the wavelength of the parent first order line, the detection limit from the Winge table in ppb and a number of stars corresponding to the order.

The program has several options, allowing a printout of the listing, and if required, information on the restrictions on the placement of the spectral windows due to the dimensions of the array and its carriage.

```

10 REM PROGRAM **ARRAYSET** TO HELP POSITION THE ARRAYS
20 INVERSE : PRINT "WARNING ": NORMAL
30 PRINT "THERE IS A CHARACTER IN THIS PROGRAM": PRINT
40 REM THE DOS DOESN'T HANDLE THE AMPERSAND WELL
50 PRINT "THAT THE D.O.S: CAN'T HANDLE"
60 PRINT : PRINT "SO PRESS CONTROL C AND RETURN"
70 PRINT : PRINT "AND TYPE:~"
80 PRINT : HTAB 10: PRINT "640&SQRG$"
90 PRINT : HTAB 10: PRINT "RUN"
100 PRINT : PRINT "IF YOU HAVE JUST LOADED IT"
110 PRINT : PRINT
120 CLEAR
130 D$ = CHR$ (4)
140 PRINT D$;"BRUNQUICKSORTHIGH"
150 REM QUICKSORT IS NOT REPRODUCED FOR COPYRIGHT REASONS.SEE REF 50
160 DIM C$(70)
170 REM ALLOWS UP TO 70 SETS OF ELEMENTAL LINES
180 I = 0
190 FOR N = 1 TO 70
200 INPUT "ENTER ELEMENT FILE NAME (ENTER DONE IF FINISHED )";C$(N)
210 REM THE FILE NAME MUST BE TAKEN FROM THE DISK CATALOG
220 IF C$(N) = "DONE" GOTO 260
230 I = I + 1
240 NEXT N
250 REM ENTER NUMBER OF ELEMENTS
260 J = I
270 A = 0
280 FOR P = 1 TO J
290 A$ = C$(P)
300 REM SELECT ELEMENTAL FILES IN ORDER
310 FOR R = 3 TO 1 STEP - 1
320 B$ = RIGHT$ (A$,R)
330 IF VAL (B$) > 0 GOTO 360
340 REM FINDS THE NUMBER OF LINES IN EACH FILE
350 NEXT R
360 A = A + VAL (B$)
370 REM SUM ALL THE NUMBERS OF LINES
380 NEXT P
390 DIM G$(A)
400 REM SET THE DIMENSION TO HOLD ALL THE LINES IN THE FILE
410 I = 1
420 FOR S = 1 TO J
430 REM DISPLAY THE ELEMENTAL FILE NAME
440 A$ = C$(S)
450 PRINT A$
460 FOR T = 3 TO 1 STEP - 1
470 B$ = RIGHT$ (A$,T)
480 IF VAL (B$) > 0 GOTO 500
490 NEXT T
500 E = VAL (B$)
510 REM FIND THE NUMBER OF LINES IN THE FILE
520 C = I:D = C + E - 1
530 PRINT CHR$ (4);"OPEN";A$
540 REM OPEN THE MAIN TEXT FILE
550 PRINT D$;"READ";A$
560 FOR I = C TO D
570 INPUT G$(I)
580 REM PUT THE FILE LINES INTO THE MAIN TEXT FILE
590 NEXT I
600 PRINT D$;"CLOSE";A$

```

```

610 REM CLOSE THE MAIN TEXT FILE
620 NEXT S
630 REM CONTINUE
640 & SQR G#
650 REM RUN THE SORT PROGRAM
660 GOSUB 680
670 GOTO 720
680 FOR I = 1 TO A: PRINT I;" ";G$(I): NEXT I
690 REM LIST ALL LINES IN SPECTRAL ORDER
700 CALL - 756
710 RETURN
720 HOME
730 PRINT "CHOOSE:-": PRINT
740 HTAB 4: PRINT "1. PRINT IT OUT": PRINT : HTAB 4: PRINT "2. POSITION ARRAYS"
: PRINT
750 HTAB 4: PRINT "3. MAKE ANOTHER SELECTION": PRINT : HTAB 4: PRINT "4. GOODEY
E": PRINT
760 INPUT "ENTER 1,2,3 OR 4 ";E
770 ON E GOTO 780,850,820,840
780 PRINT CHR$(4);"PR#1": GOSUB 680
790 REM PRINT OUT HARD COPY
800 PRINT CHR$(13); CHR$(4);"PR#0"
810 GOTO 720
820 GOTO 120
830 REM CHOOSE ANOTHER SET OF ELEMENTS
840 END
850 HOME
860 PRINT "AN ARRAY COVERS A SPECTRAL WINDOW OF 17"
870 REM PROGRAM EXCLUDES UNAVAILABLE POSITIONS
880 PRINT : PRINT "ANGSTROM UNITS."
890 PRINT : PRINT "ARRAYS CAN ONLY BE SPACED AT SPECTRAL": PRINT
900 PRINT "INTERVALS OF 250 ANGSTROM UNITS.": PRINT
910 PRINT "ACTUAL PHYSICAL POSITION ON THE CIRCLE": PRINT : PRINT "WILL BE GIVE
N ELSEWHERE": PRINT
920 PRINT "ARRAYS ARE NUMBERED FROM 0 TO 5"
930 INVERSE : PRINT "BE READY TO PRESS CTRL-S": NORMAL
940 F2 = 0
950 FOR G = 0 TO 5
960 PRINT "ENTER SPECTRAL POSITION ARRAY # ";G: INPUT F
970 PRINT CHR$(4);"PR#1": PRINT F: IF F < F2 THEN PRINT "IMPOSSIBLE TO LOCAT
E": PRINT CHR$(4);"PR#0": GOTO 960
980 F1 = F + 17:F2 = F + 250
990 PRINT CHR$(4);"PR#0"
1000 FOR I = 1 TO A
1010 IF VAL (G$(I)) < F GOTO 1060
1020 IF VAL (G$(I)) > F2 GOTO 1050
1030 IF VAL (G$(I)) > F1 GOTO 1060
1040 PRINT CHR$(4);"PR#1": PRINT "WINDOW. ";I;" ";G$(I): PRINT CHR$(4);"PR
#0": NEXT I
1050 PRINT I;" ";G$(I)
1060 NEXT I
1070 NEXT G
1080 PRINT CHR$(4);"PR#0"
1090 GOTO 730

```

LINELOC calculates the position for the array carriage on the direct reader focal plane corresponding to a spectral value.

ELEMENTINPUT is used to enter the information from the Winge table and creates the text files with up to 3 spectral orders for use with ARRAYSET.

Due to the space occupied by the text files, the programs ARRAYSET, LINELOC and ELEMENTINPUT, and the text file library are stored on a disk other than that carrying the direct reader operating system.

The program QUICKSORTHIGH is not reproduced for reasons of copyright. See reference [50].

```

10 REM PROGRAM **LINELOC** TO CONVERT SPECTRAL POSITION TO
20 REM FOCAL PLANE POSITION
30 HOME : PRINT "SPECTRAL LINE LOCATION "
40 PRINT "POSITIONS FOR THE RHS OF MOUNT"
50 D = 149.1776:CV = 4707.24
60 C = 58.8
70 INPUT "ENTER WAVELENGTH REQUIRED IN ANGSTROM UNITS";AV
80 INPUT "ENTER SPECTRAL ORDER ";T
90 AV = AV * T
100 S = (CV - AV) * 118 / 10 ^ 6
110 F = ATN (S / SQR (- S * S + 1))
120 G = D * S + C
130 PRINT CHR$(4);"PR#1"
140 PRINT AV;"ANGSTROMS = ";G;" CMS ON SCALE"
150 PRINT CHR$(4);"PR#0"
160 GOTO 70
170 REM THIS GIVES A REASONABLE FIT

```

```

10 REM PROGRAM **ELEMENTINPUT** TO ENTER SPECTRAL LINE INFORMATION
20 CLEAR
30 INPUT "ENTER ATOMIC SYMBOL ";A$
40 INPUT "ENTER NUMBER OF LINES";Q
50 N = Q * 3: DIM G$(N)
60 I = 1
70 FOR P = 1 TO Q: PRINT "ENTER LINE TYPE, WAVELENGTH IN AU, LIMITS IN PPM.
80 PRINT "(TO END ENTER...END,0,0)
90 INPUT E$,C$,D$
100 IF E$ = "END" GOTO 230
110 FOR E = 1 TO 3:F$ = STR$(E * VAL(C$))
120 IF VAL(F$) > 7620 GOTO 210
130 ON E GOTO 140,150,160
140 E$ = "x": GOTO 170
150 E$ = "xx": GOTO 170
160 E$ = "xxx"
170 G$(I) = F$ + " " + A$ + " " + E$ + " " + C$ + " " + D$ + " " + E$
180 I = I + 1
190 M = I - 1
200 NEXT E
210 PRINT
220 NEXT P
230 GOSUB 250
240 GOTO 360
250 REM STORE LINE INFO IN A TEXT FILE
260 D$ = CHR$(4)
270 PRINT D$;"OPEN";A$
280 PRINT D$;"WRITE";A$
290 FOR I = 1 TO M
300 PRINT G$(I)
310 NEXT I
320 PRINT D$;"CLOSE";A$
330 M$ = STR$(M):I$ = A$ + M$
340 PRINT D$;"RENAME";A$;" ";I$
350 RETURN
360 GOTO 20

```

APPENDIX 7

## APPENDIX 7

### POWER SUPPLIES FOR THE SIX ARRAY SYSTEM

The Apple computer came with a built in power supply that supplied:-

+5 V, 2.5 A  
-5 V, .25 A  
+11.8 V, 1.5 A  
-12 V, .250 A

The power for the six RC1024S array control boards and their auxiliary circuitry required:-

+5 V, 3.8 A  
+15 V, .45 A  
-15 V, 1.05 A

These were supplied by a LAMBDA LOT-W5152A power supply.

The 6 sets of Peltier heat pumps together required 6 V, 12 A. This was supplied by two LAMBDA power supplies, an LCS CC 01 and an LCS C 01. One supplied power to 4 sets, the other to 2.

The integration timer circuit board, the digital to analog converter and the integration time indicator system

were powered off the +5 V, +15 V and -15 V supply from a  
HEATH DIGITAL POWER MODULE EU 801-11.

