A MICROPROCESSOR BASED MULTIWAVELENGTH-DETECTOR SYSTEM FOR LIQUID CHROMATOGRAPHY

by

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To my Family and Sara

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INTRODUCTION

Many advances have taken place in liquid chromatography since its conception. To date, however, detector technology has not progressed at the same rate as has the development of new column packings or pump systems. The single wavelength fixed ultraviolet (UV) detector set to monitor 254 nm is the most commonly available commercial detector. When this type of detector responds to a change in the composition of the column's effluent, it is telling the separations chemist only that a compound or group of compounds passing through the detector absorbs at 254 nm. If a compound does not absorb at this wavelength, it goes undetected. If only a shoulder of an absorption peak occurs at 254 nm, detecting this compound will be more difficult than detecting a compound whose maximum absorption occurs at 254 nm. There is also no way to know if a particular peak is caused by a single component or an unresolved group of components. Because of these limitations, a refractive index detector is also often placed on line with the single wavelength UV detector. The combination of these two detectors can be used with some degree of certainty to determine when a separation has taken place. However, the chemist has been assured only that the separation has taken place and has received little if any chemical information that can be related to similar compounds.

Instrument manufacturers have responded to this problem by providing both adjustable wavelength and scanning-spectrophotometric detector systems. Generally, both types of detectors can cover the ultraviolet-visible spectrum from 190 nm to 900 nm. The single wavelength adjustable detector permits the operator to choose an optimal wavelength for a particular separation, permitting greater sensitivity. Nevertheless, one compound can not be distinguished from another with this type of detector. The scanning-spectrophotometric detector system can also be set to a specific wavelength, but also has the capability of scanning the detector cell over a band of wavelengths. To scan the cell often requires stopping the separation for from two to five minutes as the spectrophotometer scans through the selected band of wavelengths. The separation has only to be stopped if the characteristic spectrum of the compound in the detector cell is to be obtained. With this type of detector, the chemist can often spend more time acquiring characteristic spectra than performing the actual separation. It also requires constant monitoring by the chemist to decide when and if a spectral scan is to be performed. The solution to this problem would be to monitor a number of wavelengths simultaneously where the absorption at a particular wavelength is characteristic of a single compound or group of compounds. At the same time, the ability to scan the column effluent quickly in order to acquire a UV-VIS spectrum without having to stop the separation would be very desirable.

The goal of this work was to build a multiwavelength-detector system for liquid chromatography using a state-of-the-art microprocessor and a solid state linear photodiode array. The system had to be capable of monitoring a number of wavelengths simultaneously and of providing the ability for the operator to switch the wavelengths of interest quickly and easily. At the same time, the detector system also had to have the ability to produce an ultraviolet or visible spectrum in a suitable format on demand.

HISTORICAL

Although the desirability of a simultaneous, multiwavelength detector is very great, few detector systems commercially available today have this capability. A review by Veening (1) of commercially available detectors (1970) showed that a number of workers had been successful in coupling general purpose spectrometers and spectrophotometers to liquid chromatographs. Veening reported (2) the use of a Beckman DB spectrophotometer set for 320 nm as the detector for separating metal π complexes. Jentoft (3) used a Cary 10-11 spectrophotometer for the analysis of polynuclear aromatic hydrocarbons. The system was also capable of scanning the column effluent from 215 nm to 800 nm. Scott (4) used a modified Beckman DB and a Coleman 124 spectrophotometer for analyzing the carbohydrate content of urine and blood serum samples.

The use of spectrometers and spectrophotometers as detectors for high performance liquid chromatography (HPLC) has been successful, but most workers still use a fixed wavelength UV detector (254 nm) or a fixed wavelength UV detector (254 nm) coupled with a refractive index (R.I.) detector. The 254 nm UV detector is the most common, as it is usually supplied by the manufacturer with the liquid chromatograph. This type of detector usually has dual beams. The column effluent passes through one cell and the other cell may be used as an air or pure solvent reference. In gradient elution, the mixed solvent system can oftem be passed through the reference cell before going into the column. However, if this method of referencing is used, column pressures usually can not exceed 500 psig, because of the cell design.

With its associated electronics, these detectors can detect compounds with an absorbance less than 0.0001 O.D. The dynamic range of these detectors is typically 0.01 to 5.12 O.D.

The main disadvantage of these detectors is that only one or two fixed wavelengths (254 nm or 254 nm and 280 nm) can be monitored at one time. The 254 nm source consists of a low pressure mercury source and the 280 nm source is a phosphor-coated block that absorbs at 254 nm and emits at 280 nm. A number of photometric detectors also have the capability of utilizing filters for other wavelengths. Of course, to use a 254 nm or 280 nm detector, the compounds being separated must absorb somewhat at these wavelengths and the solvent must not, unless the reference cell is used. Likewise, changes in baseline values usually occur in gradient elutions due to changes in the refractive index of the solvent system.

Differential refractometers (R.I.) are almost as general in purpose as UV photometric detectors. They are available in both single and dual-beam models. One of the greatest disadvantages of the R.I. detectors is its extreme sensitivity to small temperature variations. Typically, the column effluent, reference sample stream and refractometer must be thermostated. Problems can also occur if a gradient elution is performed even when the reference cell is flushed with solvent prior to going onto the column. This is due to the gradient in composition between the reference cell and the detector cell. Other types of detectors that have been used in HPLC include flame ionization, heat of adsorption, fluorescence, conductance, radiochemical and polarographic systems. These detectors are not of as general use as the UV and/or R.I. detector, because of their specificity, complexity or cost. For a more complete review of HPLC detector systems see (5,6).

As the popularity of HPLC increased, more and more researchers recognized the limitations of the UV and R.I. detectors. In 1974, Rogers projected the use of vidicon tubes for ultraviolet and visible detectors (7). In the same year, Dessy described the use of a linear photodiode array for a HPLC detector (8). Carr reported the use of a Variscan detector system (Varian Associates, Palo Alto, CA) for analyzing vitamins and hexachlorophene (9). With this system, wavelengths were chosen where the absorption of a particular compound was the greatest. Plots of absorbance versus time for a particular wavelength were presented. No complete spectra of any of the components that were separated were reported. Even so, the Variscan system was capable of scanning from 210 to 780 nm with a lamp change at 300 nm, at speeds of from 10 nm/min to 100 nm/min (10). The Variscan detector has also been used on line with a 254 nm UV detector (11). A simialr system, described by Janzen and Foley (1976) (12), is currently being produced by the Milton Roy Company. Aldous and Garden have also announced their preliminary work on using photodiode linear array (13) as a HPLC detector, but nothing else has been reported to date. More recently, Denton et al. reported the use of a commercially available oscillating mirror-photomultiplier detector (14). The system consisted of a Harrick Rapid Scan Spectrometer and a GaAs photomultiplier tube. A wavelength range of 200 to 900 nm could be scanned 218 times per second.

As can be seen, there are a number of different methods for making fast scanning, multiwavelength detectors. The three basic detector systems are:

1) Mechanical Scanners.
   The mechanism of the detector scans the radiation across a single detector element. The Variscan and oscillating mirror are of this type.
2) Linear Photodiode Arrays.
   A portion of the ultraviolet or visible spectrum (50 - 600 nm bandwidth) is dispersed over the length of the array.
3) Vidicon Detectors.
   Like the photodiode array, a band of radiation is dispersed upon a two dimensional silicon target. Compared to the photodiode arrays, vidicon tube technology (similar to a television camera tube) is the more highly developed.

Although there is much interest in the vidicon and photodiode array detectors, there are only two detector system commercially available that use vidicon tubes and none using photodiode arrays.

All three types of detector have been used to solve chemical problems. They have found applications in atomic absorption spectroscopy, flame/plasma emission spectrometry and stopped flow kinetic studies. Malmstadt has used a GCA/McPherson scanning monochromator for a flame spectrometer (15) and Dye has used a Perkin-Elmer monochromator (16) for stopped flow studies. Vidicon spectrometers have been fully described for a number of branches of spectroscopy (17-23). Photodiode arrays have also been reviewed (24,25), characterized (26) and applied to chemical problems (27-30).

Microprocessors

Even though microprocessors were introduced only in 1971, they have been met with wide spread acceptance. Their computational and control capabilities and small size are reasons why they are currently being incorporated into nuclear weapon controllers, steel mill presses, "smart" cash registers and analytical instrumentation. It has been predicted that by 1985, microprocessors will be incorporated in more than half of all analytical instrumentation. Today, microprocessors can be found in instruments manufactured by Varian Associates, Perkin-Elmer and Princeton Applied Research.

Although minicomputers have been incorporated into some chemical instrumentation by some manufacturers, they have been applied only to high priced instrumentation, typically in gas chromatography-mass spectrometry (GC/MS), electron spectroscopy for chemical analysis

(ESCA) and nuclear magnetic resonance spectroscopy (NMR). This lack of acceptance of minicomputers is due in part to their high cost and large size. A comparison of current minicomputer and microprocessor technology can be found in Table 1.

Table 1

MINICOMPUTERS(PDP-8/E) vs MICROPROCESSORS(LSI-11)
(Digital Equipment Corporation)

	LSI-11	PDP/8-E
Size (cu.ft.)	1	2.7
Weight (lbs.)	20	90
Cost	$900	$2500
Power required	100 watts	500 watts

By decreasing the cost, size and power requirements and by increasing the computational power of the computer, the number of possible applications has become almost unlimited. Therefore, we might someday find a microprocessor in a simple single beam, manually scanned spectrometer.

Chemical Systems Studied

With the construction of a new liquid chromatography detector, chemical studies had to be performed to characterize the detector. The compounds studied had to be synthesized within a reasonable amount of time and in reasonable yield. A ten or fifteen step synthesis would have been unacceptable. At the same time, the reactions studied had to involve starting materials, intermediates or products with appreciable visible spectra. Colored compounds were required due to the use of glass optics in the spectrometer. For these reasons, the reduction of nitrobenzene to azobenzene was studied. Because of the complexity of the reaction and the presence of intermediate products, a spectrum of the reaction mixture could not be taken directly. During the reduction of the nitrobenzene, aliquots of the reaction mixture where obtained. The organic compounds were dissolved in hexanes and then separated using HPLC in conjunction with the multiwavelength detector. Characteristic spectra of azobenzene could than be obtained.

The reduction of a 2,2'-dinitrodiphenylmethane to a dibenzo(c,f)-(1,2) diazepine was also studied. Like azobenzene, the dibenzodiazepine was colored and the reduction reaction complex.

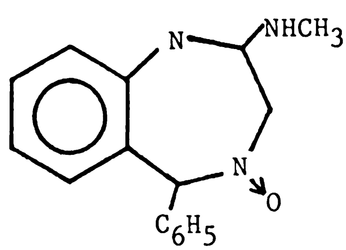
The separation of commercially available food dyes was also attempted with the multiwavelength-detector system. The composition of the dyes was unknown and the mixture was too complex to obtain characteristic spectra without separating the dyes by HPLC.

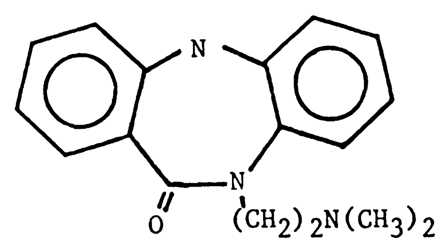
Azobenzene and related compounds

Much of the interest in azobenzene and azobenzene-like compounds has been due to the dyestuffs industry. Starting from nitrobenzene, two important starting materials for dyes, aniline and benzidine, may be synthesized. Neither synthesis is difficult and both are being run on a commercial scale today. The reactions of these compounds to form dyestuffs have been documented for many years (31,32). Some of the more recent work has involved studying the rearrangement of azobenzene and hydrazobenzene (33-36), the effect of catalysts on the reduction of nitrobenzene to azobenzene (37-39) and the mechanism of the nitrobenzene reduction to azobenzene and hydrazobenzene (40-43).

Diazepines

The group of compounds called diazepines is a large and diverse one. Some members of the family have been found to be physiologically active and are being used in medicine today.





Chlordiazepoxide

Anticonvulsant

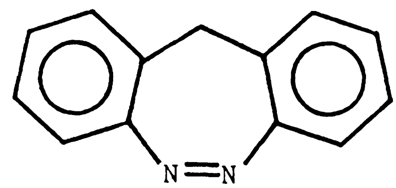
Dibenzepine

Antidepressant

Physiologically Active Diazepines

Figure 1

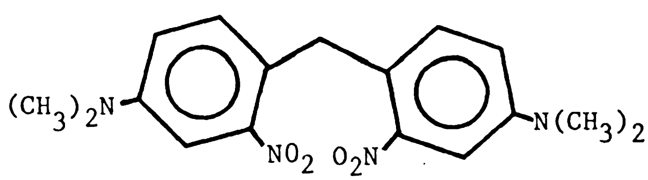
A subgroup of the diazepine family are the 11H-dibenzo(c,f)-(1,2)diazepines (Fig. 2)



11H-dibenzo(c,f)(1,2)diazepine

Figure 2

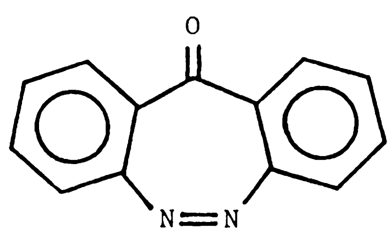
In 1894, Pinnow(44) reported the nitration of 4,4'-methylenebis(N,N-dimethylaniline) with a solution of potassium nitrate in sulfuric acid at 0^{o} . After neutralization with sodium carbonate, the product, 2,2'-dinitro-4,4'-methylenebis(N,N'-dimethylaniline), was isolated.



2,2'-Dinitro-4,4'-methylenebis(N,N'-dimethylaniline)

Figure 3

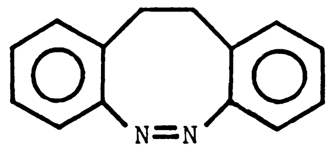
Soon afterward, Duval reported reactions involving 4,4'-methylenedianiline and 4,4'-methylenebis(N,N-dimethylaniline) (45-47). Little was done in the field of dibenzo(c,f)(1,2)diazepines until Theilacker and Korndorfer (48) reported the synthesis of 11*H*-dibenzo(c,f)(1,2)diazepine by reducing 2,2'-dinitrodiphenylmethane with lithium tetrahydridoaluminate (LAH) to the diazepine. Johns and Markham reported in 1964 that dibenzo(c,f)(1,2)diazepine-11-one could be produced by the alkaline glucose reduction of 2,2'-dinitrobenzophenone (49).



2,2'-Dinitrobenzophenone

Figure 4

Lowrie reported (50) the synthesis of a number of derivatives of both dibenzo(c,f)(1,2)diazepine and dibenzo(c,g)(1,2)diazocine (Fig. 5).



11$\underline{H}$-Dibenzo(c,g)(1,2)diazocine

Figure 5

The derivatives reported were synthesized by reacting substituted malonyl chlorides with the 5,6-dihydro derivatives of both the diazepine and the diazocine.

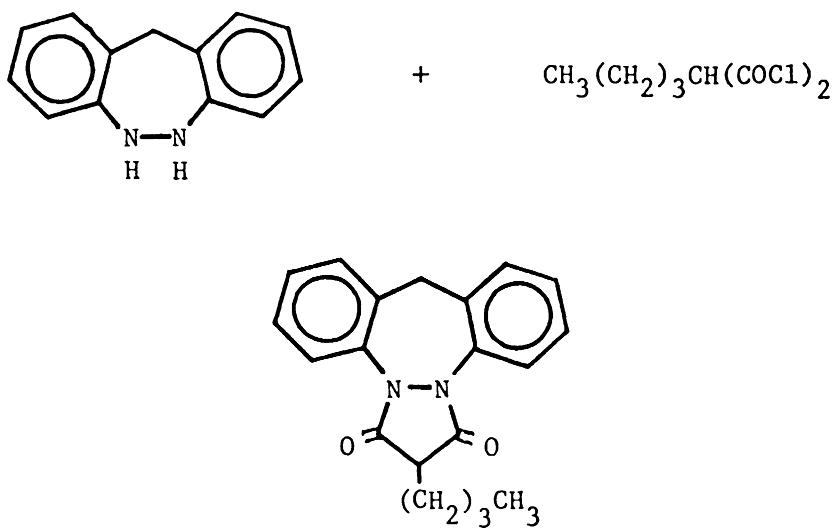
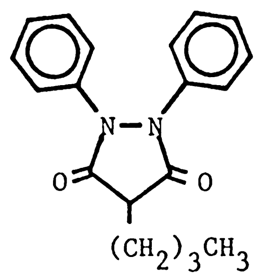


Figure 6

These compounds were synthesized so that their antiinflammatory behavior could be compared to that of phenylbutazone (4-butyl-1,2-diphenyl-3,5-pyrazolidinedione) (Fig. 7).

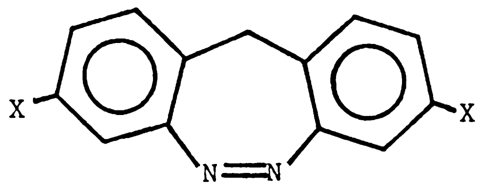


4-Butyl-1,2-diphenyl-3,5-pyrazolidinedione

Figure 7

The patent rights to similar compounds were assigned to the G.D. Searle & Co. by Lowrie in 1965 (51).

In 1964, Catala and Popp (52) reported the synthesis and characterization of a number of 3,8-dihalo-11H-dibenzo(c,f)(1,2)diazepines (Fig. 8).



X = F,Cl,Br,I

3,8-Dihalo-11*H*-dibenzo(c,f)(1,2)diazepine

Figure 8

Some of the 5-oxide, 11-one, 5,6-dihydro and 5-oxide-11-one derivatives were reported. No work was reported on the 3,8-bis(N,N-dimethylamino) substituted diazepine. The dihalo substituted diazepines were then subjected to an extensive synthetic study (53-55). A review of the 1,2, 1,3 and 1,4 dibenzodiazepines has also been written (56).

GENERAL SYSTEM OPERATION

The general detector system may be seen in Fig. 9. After the detector system paper tape (DOS/EXEC) has been loaded into the computer's memory using the PAL8 to 8008 Macro Loader, the user has to establish some operating parameters for the system. Basically, these are the Time Between Spectra (TBS) in seconds, the integration time, in milliseconds, and the array numbers to monitor during the separation. These values are all typed in on the Teletype and stored in the computer's memory.

The TBS is equivalent to choosing the speed of a strip chart recorder that is being used in a chemical experiment. It determines the resolution of the system and is influenced by the duration of the experiment. If an experiment takes 24 hr, the recording speed would probably be set to one or two inches per hour, not one or two inches per minute. The computer can acquire only 256 spectra under the Real Time Clock's control. This number would be divided by the expected duration of the separation, the result being a reasonable TBS. The ITEG is the duration of time the light from the detector cell strikes the linear photodiode array (PDA). It may be thought of as an electronic shutter. The ITEG and its determination will be discussed more thoroughly later on in this work.

The arrays of interest can be correlated to specific wavelengths.

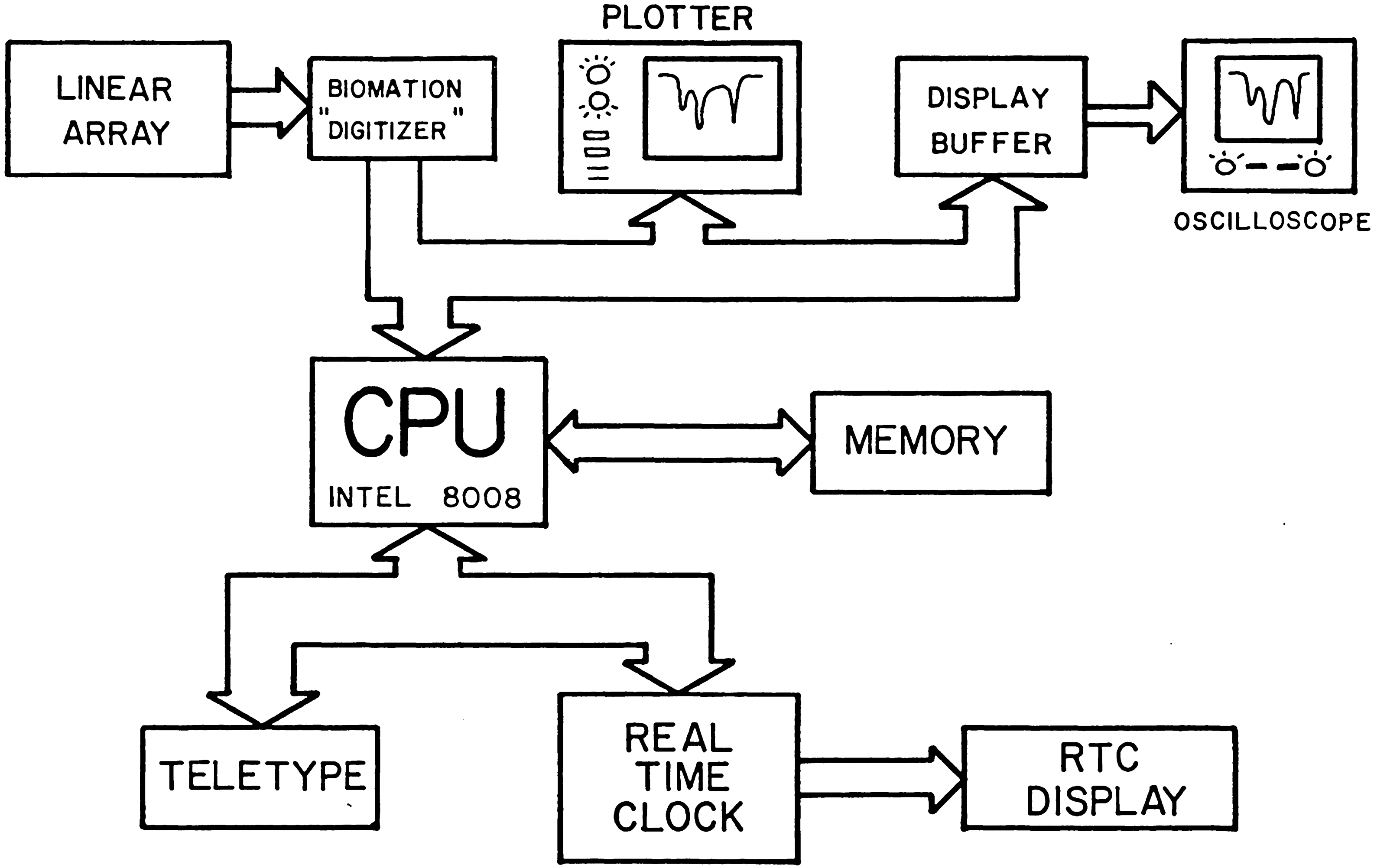


Figure 9, MICROCOMPUTER BLOCK DIAGRAM

There is no absolute method that can be used to determine which arrays correspond to what wavelengths. Instead, a standard with known absorbance peaks is placed in the light path and the array numbers where maximum absorbance occurs are noted. The spectrometers bandwidth is defined as the difference in wavelengths that strike the first and the last (256th) array. The bandwidth would be 200 nm whether a wavelength range of 400 nm to 600 nm or 650 nm to 850 nm were covered. With the photodiode array used, there are 256 photodiodes covering 200 nm, which means that each photodiode covers 0.75 nm. If the peak of a standard is at 520 nm (the 100th array), then a peak at 535 nm must reside at the 115th array. Because the spectrometer used a grating, there is a linear relationship between the array numbers and wavelengths. Therefore, the correlation between the array numbers and wavelengths is relatively simple, but it requires a standard with a known absorbance or transmittance spectra.

Most computers cannot perform two operations at the same time. The microcomputer chosen for this work could not continuously display spectral data on the oscilloscope and at the same time accurately time the Time Between Spectra (TBS). For this reason, a Real Time Clock (RTC) was constructed for the microcomputer. This type of device was not available for the microcomputer used, but it is often available for other computers from the manufacturer. Also, most computers do use some type of real time clock, so that events can be accurately and reproducibly timed. The RTC that was constructed can be loaded with any time between one and 256 seconds, in one second intervals. The output of the RTC drives a display so that the operator knows how much time has elapsed since the RTC was started. As might be expected, in this particular application, the real time clock is loaded with the value of the Time Between Spectra (TBS) that the user typed into the computer. When the RTC "times out", an interval of time equal to the TBS has elapsed, notifying the computer that a 256 point spectrum should be acquired.

The linear photodiode array may be thought of as 256 pairs of photodiodes and capacitors in parallel. Initially, all of the capacitors are charged and can be discharged only be light striking the photodiodes. As light strikes the photodiodes for longer and longer periods of time, the capacitors become more discharged. The intensity of the incident radiation is measured by how discharged the capacitors become within a given period of time. This measurement is actually performed during the sweep out of the array. During the sweep out, the amount of charge required to recharge the capacitors completely is measured.

If light strikes the array for too long a period of time, the capacitors become completely discharged and no analytical information can be obtained. Because the Time Between Spectra (TBS) is usually 10 to 30 seconds, the capacitors are completely discharged when the Real Time Clock "times out" and a spectrum must be obtained. Therefore, the first operation performed by the computer after the interrupt occurs is to sweep out the array, which causes all of the capacitors to become completely charged again. The computer then waits for the integration time period to be over, one to ten milliseconds. This integration time may be thought of as an electronic shutter. The capacitors were completely recharged, the "shutter" was opened for the integration time and then the "shutter" was closed when the computer began the sweep out of the array. After the integration period was over, the varying voltage output of the linear photodiode array reflects the transmittance spectra of the compound currently passing through the detector cell. This analog voltage cannot be directly stored in the computer. It must first be converted by means of an analog-to-digital converter (the Biomation Transient Recorder) to digital values that the computer can store in its memory. Because of the short time available to perform the analog-to-digital conversion (2 μsec or 20 μsec), the Biomation converter had to be used. With this type of converter, a 256 point spectrum can be converted into digital values in 512 μsec or 5.12 msec. The spectral data stored in the transient recorder are then transferred, by means of an assembly language program, from the Biomation Transient Recorder's (BTR) memory to the computer's memory. When the data have been stored in the computer's memory, it can be typed out on the Teletype, punched on paper tape, plotted or displayed on the oscilloscope.

Generally, the user wants to monitor two or three wavelengths (arrays), but not all 256. Therefore, the computer has to sort through all 256 data points in memory, to find the transmittance values of the array numbers specified by the user. One deficiency of the information stored in the memory is that it represents not only the transmittance of the compound in the detector cell, but also the responsivity of the silicon linear photodiode array. With this type of detector, as with most others, there is a non-linear response to varying wavelengths. Since a 200 nm band of radiation is dispersed along the length of the array, the output from array to array will not be the same. For this reason, many commercial instruments are dual beam, utilizing two identical detectors, so that the non-linear response due to the varying wavelengths is cancelled out, by subtracting the signal from the pure solvent reference from the signal from the sample cell.

After the information stored in the computer's memory has been corrected for the non-linear response of the array (using the Baseline Correction Constants (BCC) previously determined), the computer finds the data values corresponding to the array numbers that the user selected to monitor. These data values are then plotted on the X-Y plotter. To perform a plot, the computer has to supply the plotter with analog voltages that produce the pen deflections. These analog voltages are produced by digital-to-analog converters. The same pair of converters (one converter for the X-axis and one for the Y-axis) also supplies the analog voltages necessary to drive the oscilloscope display.

The oscilloscope is used to display the complete 256 point spectrum and the plotter is used to plot only the variance in transmittance at the user selected array numbers (wavelengths). The plotter can plot data at the rate of one or two points per second. For a visual display of the data, over 15,000 data points per second (256 points per spectrum, 60 times per second) must be output to the oscilloscope. Due to the large difference in rates of data output, the analog voltages from the digital-to-analog converters are routed to the plotter only when the computer is performing a plot function. Under computer control, the rate of data output can be slowed down, so that the plotter can plot the data. This means that the analog voltages from the digital-to-analog converters are not simply routed to both the plotter and oscilloscope, but must go through a data router or demultiplexer. At the same time, trying to put out over 15,000 data points to the oscilloscope every second was a severe burden to the microcomputer. A display controller was therefore constructed to relieve the computer of the task of producing the oscilloscope display. With this controller, the computer wrote the spectral data into the controller once to load the display buffer's memory. After the buffer was loaded, the computer could do any other operations requested by the user and the display would continue to operate. A summary of these operations and the time required can be seen in Figure 10.

Conceptually, the system is very simple and its tasks are well defined. Unfortunately, the implementation of these system criteria took many months to implement in electronic hardware and computer software. A large amount of additional time then had to be spent debugging the system and improving it to the point of being a viable multiwavelength-detector system.

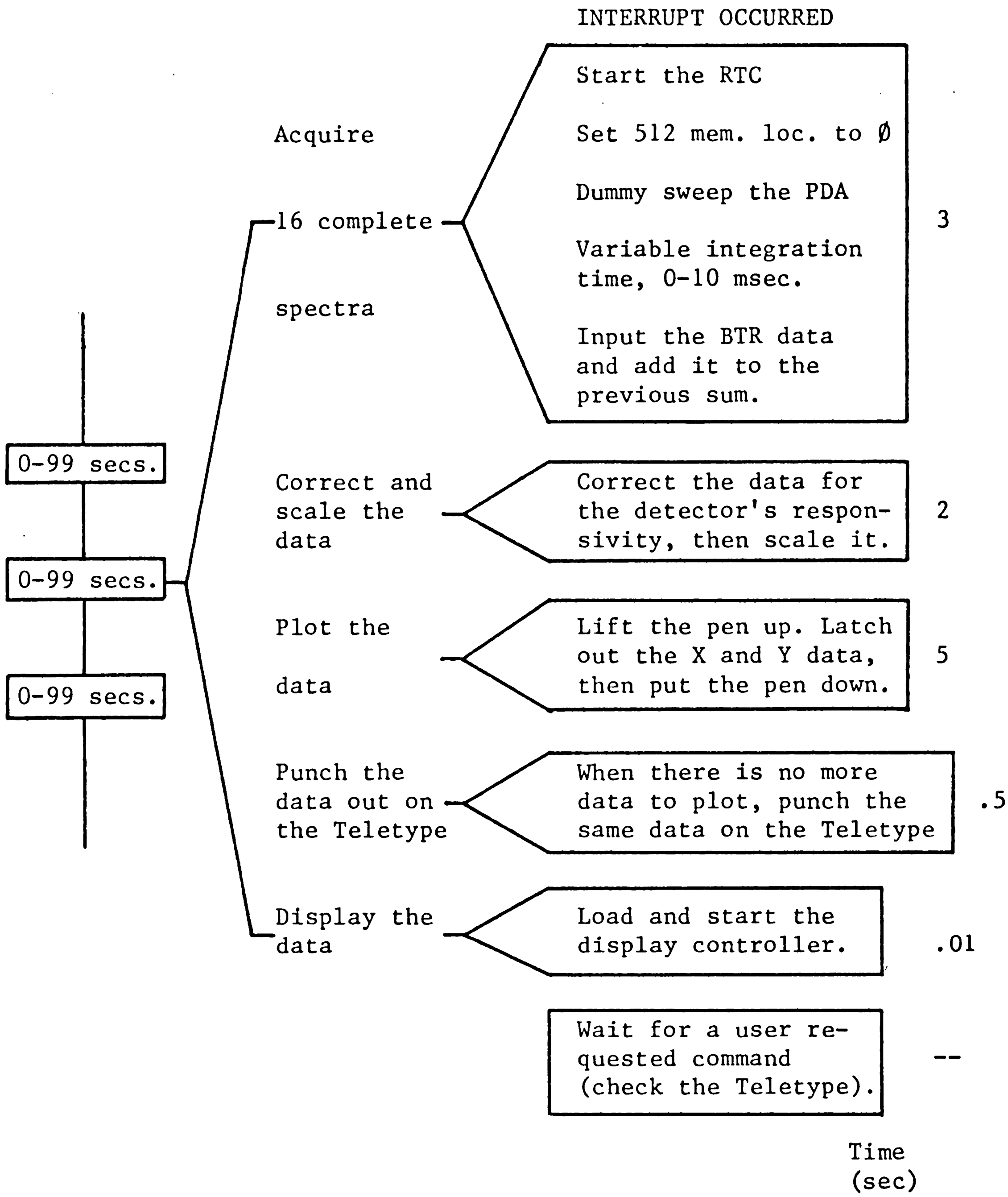


Figure 10, Operations and time required to service a Real Time Clock interrupt

COMPUTER RELATED ELECTRONICS

A Control Logic Inc. Series M 8008 microcomputer was used as the computational and control element of the detector system. It was equipped with a Console Card (LCC-514), a 20 ma current loop Teletype controller and a Model 33ASR Teletype. The computer had 4,096 words (8 bit words) of read/write (R/W) memory and 1,024 words of erasable programable, read-only memory (EPROM - 1702A). The R/W memory was contained on three LRM-598 cards, with the additional 1,024 words of R/W memory added according to Fisher's method . Paper tapes of the Detector Operating System/Executive (DOS/EXEC) were loaded into R/W memory using the Teletype's paper tape reader. In addition, data were also stored in R/W memory and a debugger and paper tape loader were stored in EPROM. Signals to and from the computer were carried by a 44 wire flexible cable-paddle card assembly.

The interface electronics were wire wrapped on perforated finger cards (#12846, Vero Electronics, Hauppage, NY). Vero edge connectors (54640LL 40-40) were also used and mounted in a Vero VR/3A/4U/L card cage. Power for the interface electronics was provided by dual DPS-2A power supplies (Environmental Products, Glenwood Springs, CO) equipped with output protection diodes in series with the supplies. A Heath IP-18 adjustable power supply was also used (Heath Co., Benton Harbor, MI).

The DPS-2A's provided the +5 V for the Transistor-Transistor Logic (TTL) and the IP-18 provided the +15 V required by the Digital-to-Analog Converters (DAC). All of the interface logic was constructed using standard 7400 series TTL. All of the logic is based on positive true logic, +5 V = 1, 0 V (GND) = 0. The DACs were model DAC-371-8 (Hybrid Systems, Burlington, MA) and the MOS memories used in the display controller were static 256x1 R/W memories (1101A2). Power for the MOS memories was provided by the -9 V CPU power supply. Peripheral devices used with the microcomputer system (Fig.9) include a Telequipment D61 oscilloscope used for the CRT display, a Hewlett Packard 7035B X-Y recorder and a Biomation 610B Transient Recorder (BTR).

A Reticon 256-A array used in conjunction with a CASH-1 amplifier, RD-4 and RC-10 (1972, Reticon Corp., Sunnyvale, CA) formed the basic building blocks of the detector. The optics and power supplies for use with these modules have been previously described (58,59). During the course of this work, three different lamps were used as light sources, a Sylvania C-25 25 watt Zirconium arc lamp, a G.E. T1034 tungston bulb and an Aris 1255H3 (Aris Inc., Des Plaines, IL) quartz lamp. The latter two lamps were powered by 12 V Saunders Associates 3018104P1 power supplies.

Biomation and Linear Array Electronics

The basic building block of the detector was the 256 element linear photodiode array. The array contained 256 individual photodiode-capacitor pairs, with the photodiodes being 0.001" wide and 0.017" high. They were arranged on 0.001" centers. When power was applied to the array, all 256 capacitors charged completely. As incident radiation struck the array, the photodiodes conducted, causing the charged capacitors to begin discharging. The stronger the radiation, the faster the capacitors discharged. After an appropriate time, often termed the integration time, the array was swept out. The integration time was typically one to 10 msec, the time being determined by the intensity of the incident radiation. This involved the sequential accessing of each capacitor, using a common "video" line, amd measuring the amount of charge required to completely recharge the capacitors. During the process of sweeping out, all of the capacitors became completely recharged, ready to be swept out again.

The video output of the linear array integrated circuit was then processed by the Reticon modules. These converted the pulsed output of the array to a step voltage output. The modules also provided all of the clocking and synchronization signals so that the array operated without any additional electronics. However, this mode of operation was not suitable for use with a microcomputer system, because the microcomputer would not know which array produced what output voltage. For this reason, the manufacturer provided for the external control of the array circuitry. The photodiode array (PDA) could be driven by an internal or external clock. Internal frequencies, those provided on the Reticon modules, ranged from 2 KHz to 2 MHz. An external clock that was within this range of frequencies could be supplied by the user. The trigger source (TRIG) could also be provided by the modules or the user. In the internal mode, it is normally supplied every 256 clock cycles (one clock cycle per array). The user could also supply a short (less than on microsecond) pulse to trigger the beginning of the sweeping out of the array. The trigger pulse had to be a negative going TTL signal.

Unfortunately, the analog voltage output of the PDA is not compatible with the digital microcomputer. The interface between the two devices was the Biomation Transient Recorder (BTR) (Fig. 11). The BTR converted the analog voltage output of the PDA into a six bit binary word. This six bit value could represent the analog voltage to within ± 1.6% (one part in 64). The digital value once determined, was stored in a 256 word x 6 bit recirculating shift register memory. This memory in the BTR could then be accessed by the microcomputer. The microcomputer must also be capable of controlling the BTR along with the PDA. The signals provided for this control task are ARM, TRIG, FLAG and WORD COMMAND (WC).

The ARM signal prepares the BTR to accept a trigger (TRIG) pulse. The TRIG pulse begins the sequence of performing an analog-to-digital conversion on the analog voltage output of the PDA and saving the value in the shift register memory. When 256 data values had been

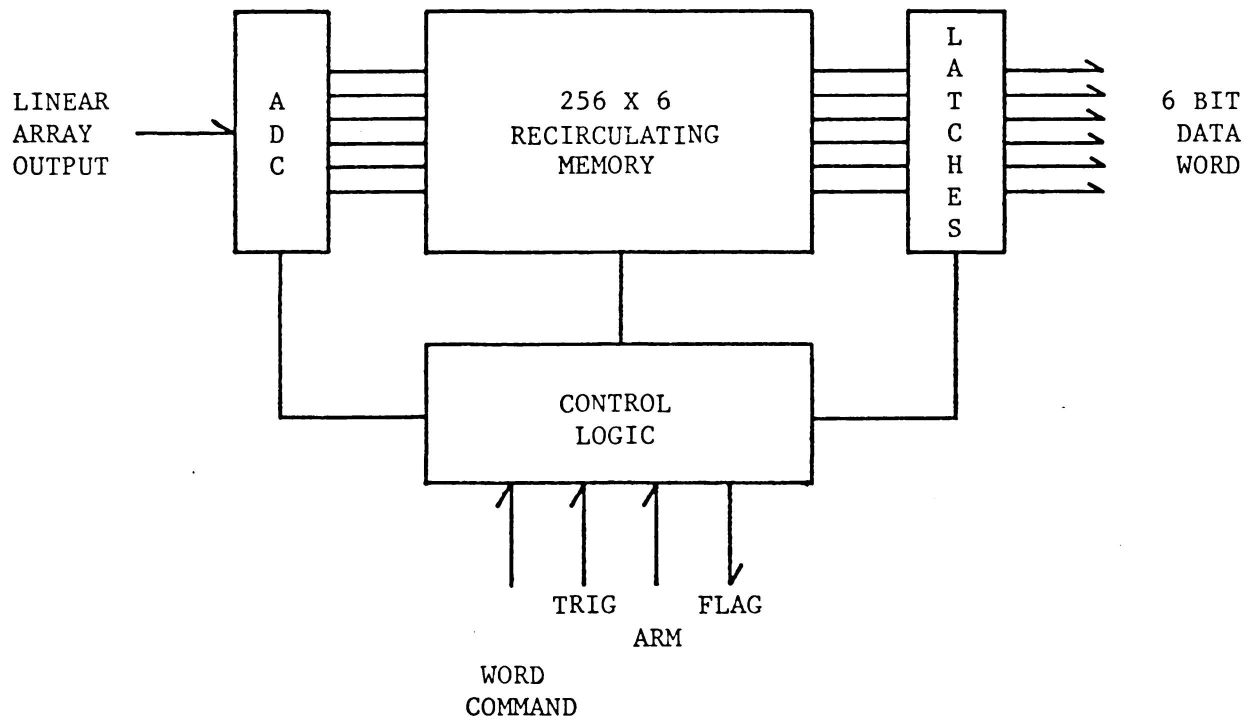
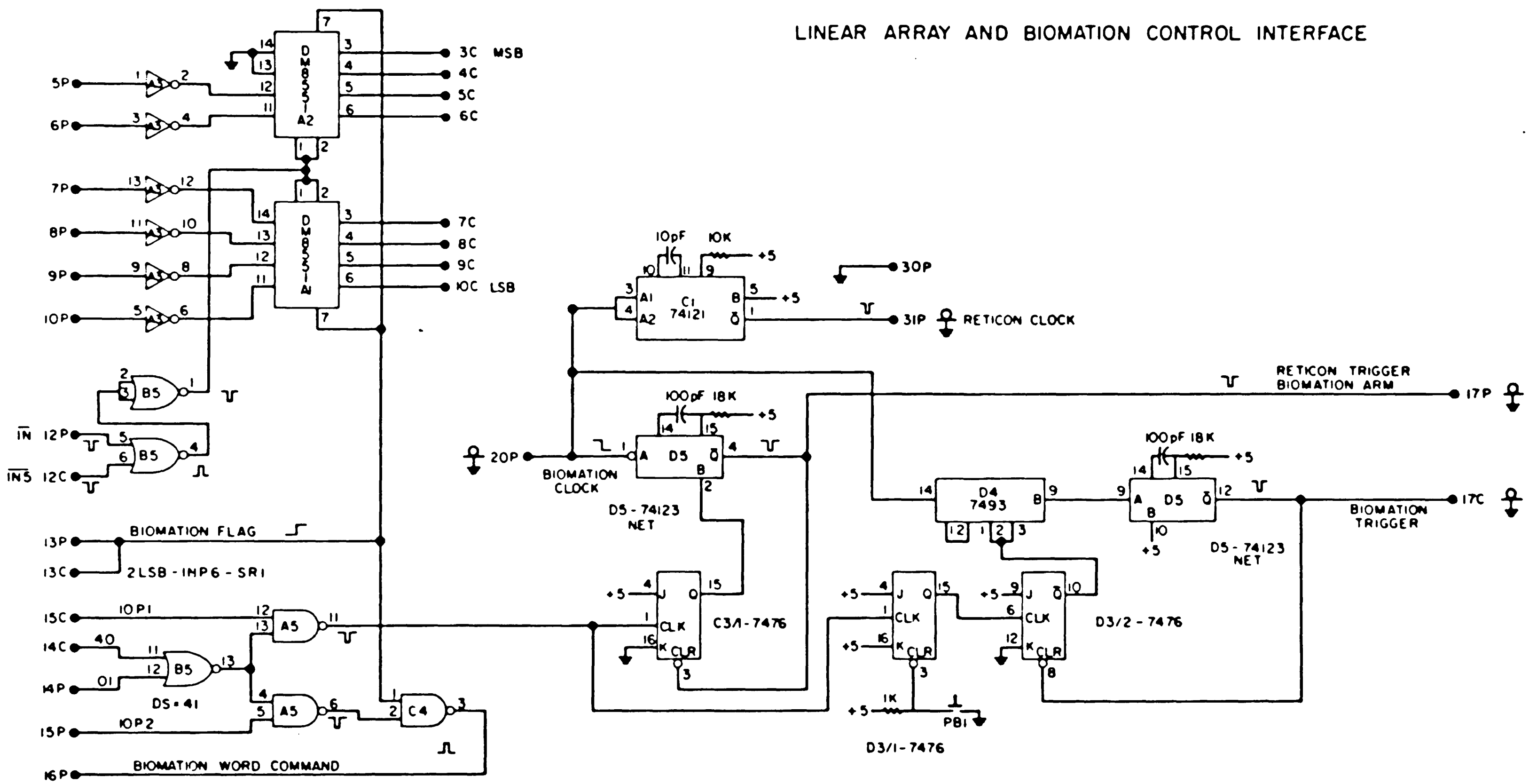


Figure 11, BIOMATION TRANSIENT RECORDER BLOCK DIAGRAM saved, the FLAG signal went to a logic 1. This was sensed by the microcomputer, and the microcomputer began the process of retrieving the data values from the BTR's memory and storing the data in its own. After the CPU inputs the first data word via a Tri-State input port, it provides a short positive pulse to the BTR Word Command (WC) line to request the next successive word from the recirculating memory. In the worst case, the memory would have to be completely recirculated before the next data value could be accessed. To input 256 data words could then take from 0.131 to 1.31 sec, depending on the speed at which the PDA and the BTR function (500 KHz or 50 KHz). After all 256 data points were stored in the CPU's memory, various mathematical , utility and I/O routines could access the data and manipulate it.

Due to the speed at which the PDA was swept out (512 μsec or 5.12 msec), the PDA, BTR and microprocessor all had to be synchronized. The following interface electronics accomplished this task.

When power was turned on, many of the flip-flops and counters of the PDA/BTR interface (Fig. 12) were in unknown states. For this reason, a self-cleaning feature was incorporated into the control logic. The desired initial state of C3/1 was Q=0. If Q=1, D5 was enabled and the Biomation Clock (BC) could trigger D5. The output of D5 ($\overline{Q}$) caused flip-flop C3/1 to be cleared and Q of C3/1 went to a 0. If flip-flop D3/2 came up with $\overline{Q}$ = 0, then the 7493 counter (D4) was enabled and therefore it counted the number of BC pulses. The counter (D4) acted as a divide-by-4, and after it had counted up



LINEAR ARRAY AND BIOMATION CONTROL INTERFACE
3C MSB
4C
5C
6C
7C
8C
9C
10C LSB
DM8551 A2
DM8551 A1
5P
6P
7P
8P
9P
10P
IN 12P
IN5 12C
13P
13C
BIOMATION FLAG
2LSB - IMP6 - SR1
15C
14C
14P
15P
16P
10P1
40
01
10P2
DS-41
BIOMATION WORD COMMAND
10pF
10K
+5
C1 74121
30P
31P
RETICON CLOCK
RETICON TRIGGER
BIOMATION ARM
17P
100pF 18K
20P
BIOMATION CLOCK
D5 - 74123 NET
D4 7493
17C
BIOMATION TRIGGER
C3/1 - 7476
D3/2 - 7476
D3/1 - 7476
1K
PB1

Figure 12

to four BC pulses, the negative edge of the B output triggered the O.S., D5. The negative pulse output of D5 caused D3/2 to be cleared, so that $\overline{Q}$ = 1. Only flip-flop D3/1 had to be cleared by hand, using PB1, because we could never be assured that the above clearing process would be neccessary each time the power was turned on. Therefore, the pulses mentioned may not always be available to clear D3/1.

When a DS41/IOP1 was issued by the CPU, Q of C3/1 went to a 1, enabling D5. The BC continuously clocks C1 and D5. When the Q output of C3/1 is a 1, D5 was enabled, and the O.S. produced a short negative pulse which armed the BTR and triggered the initiation of a sweep out of the PDA. The same pulse also caused C3/1 to be cleared. Because the Biomation was not triggered, the video output of the PDA was ignored. However, because the PDA was swept out, all of the capacitors in the array became completely recharged. At the same time C3/1 was clocked, D3/1 was also clocked, and the Q output of D3/1 went from a 0 to a 1. This logic transition did not trigger D3/2, therefore, $\overline{Q}$ of D3/2 remained at a 1 and the counter D4 remained in the cleared state. The purpose of the above sequence of events was to arm the BTR and cause the array capacitors to become completely recharged. Remember that the array was last swept out from 15 to 99 seconds ago (the user specified Time Between Spectra) so all of the capacitors in the array were completely discharged.

With the capacitors of the array recharged, we waited for a period of from one to ten msec before sweeping out the array again. This time, when the array was swept out, the video output of the array was a visible spectrum of the column effluent. Note that by varying the integration time, we could increase the response which the PDA had to a low concentration sample. However, this increase in response could not exceed the signal-to-noise ratio inherent to the PDA. The integration time that the computer waited was spent executing a software timing loop. When the software loop had timed out, a DS41/IOP1 was again issued by the microcomputer. Flip-flop C3/1 was again clocked and then cleared by D5. The negative pulse produced by D5 also caused the BTR to be armed again, and the PDA was also swept out again. The only difference between the first and second DS41/IOP1 was in the state of D3/1, D4 and D5.

After the first DS41/IOP1 pulse, Q of D3/1 went from a 0 to a 1. The second DS41/IOP1 caused a 1 to 0 transition of Q to occur. This negative edge caused D3/2 to be clocked, $\overline{Q}$ of D3/2 going to a 0. This permits D4 to be clocked by the BC. Four BC pulses later, D5 was pulsed by the negative edge of the B output of D4. The resulting negative pulse caused the BTR to be triggered. The video output of the PDA was then converted into digital values by the BTR, which were eventually read into the microcomputer's memory.

The purpose of the BTR/PDA interface was to sweep out the PDA every time a DS41/IOP1 was issued by the CPU. Every other time, when the DS41/IOP1 was issued, the BTR was triggered, and the video output of the PDA converted into digital values. When this was done, we waited four clock pulses after the PDA was triggered before the PDA was triggered. This four-clock pulse-delay was for the purpose of skipping the digitizing of the video output of four "dummy" arrays built into the PDA integrated circuit. The analog output of these dummy arrays did not vary with changes in the intensity of the incident radiation (58,59).

After the video output of the PDA was digitized into 256 words, the flag output of the BTR went from a logic 0 to a 1. This was used by the microcomputer to sense the availability of data from the BTR. A software routine similar to the following was used to sense this flag.

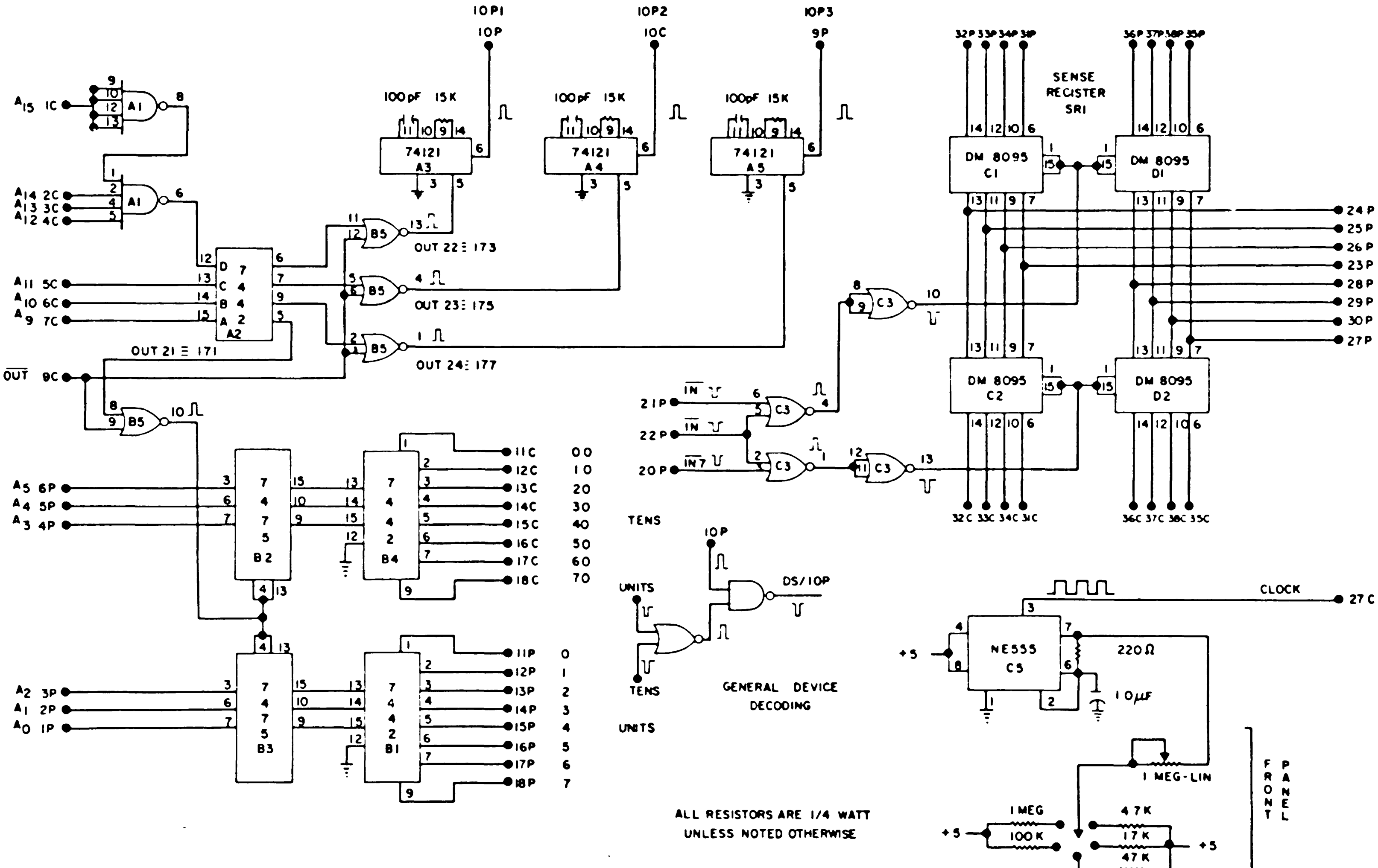
```
FLAGWAIT, INP6   /GET THE SENSE REGISTER
          ANDI   /IS THE FLAG = 1 ?
          002
          JPTZ   /NO, TEST IT AGAIN
          FLAGWAIT
          Ø
          INP5   /YES, GET THE DATA
```

After the data from the BTR was read into the microcomputer, the BTR WC line was pulsed with a DS41/IOP2 to request the next word from the BTR's memory. This next word was then loaded into a data buffer contained within the BTR and the BTR flag again went to a logic 1. This procedure was repeated until 255 words were transferred between the BTR and the microcomputer's memory. The 256th word was lost because the flag went to a logic 1 for only 100 nsec, which was far too short for the microcomputer to sense.

Device Decoder Electronics

The basic 8008 microprocessor had 32 signals that could be used to control outside world devices (24 output instructions and 8 input instructions). The Device Decoder (Fig. 13) additions were added so that the processor was capable of issuing up to 192 pulses to control Input/Output (I/O) devices. The electronics of the Device Decoder latch (B2,B3) a six bit binary word, which was in the A register of the 8008 prior to the OUT 21 instruction being executed. A1 enables A2 only during the OUT 20 - OUT 27 instructions and A2 enables the latch (B2,B3) only during an OUT 21 instruction. The latched data were then divided into two 3-bit bytes, which were then decoded into eight separate outputs by B1 and B4. Therefore, if an octal 043 was in the A register and an OUT 21 executed, pin 5 of B4 (40) and pin 4 of B1 (03) would be the only outputs of B1 and B4 to go to a logic 0 (gnd). These levels were the Device Select or DS levels. Three program controlled pulses (Input/Output Pulses or IOP) could also be created by pulsing the inputs of A3, A4 and A5 with a positive edge trigger pulse. These trigger pulses were generated by the instructions OUT 22, OUT 23 and OUT 24. By combining these pulses with the above DS levels, 192 separate I/O pulses could be generated. A comparison of pulse generating methods before and after the addition of the Device Decoder is shown in Fig. 14.

The maximum frequency of the pulses generated by the unmodified hardware was about 10 KHz. With the modified hardware, we could generate pulses at a 50 KHz rate. The advantages of the modified method



DEVICE DECODING ADDITIONS, INPUT PORTS
AND ADJUSTABLE R-C CLOCK

Figure 13

Before		After	
MVIA		MVIA	
001		043	
OUT XX		OUT 21	
XORA		OUT 22	First Pulse
OUT XX	First Pulse	OUT 23	Second Pulse
MVIA		OUT 24	Third Pulse
002			
OUT XX			
XORA			
OUT XX	Second Pulse		
XORA			
OUT XX			
MVIA			
004			
OUT XX			
XORA			
OUT XX	Third Pulse		

Figure 14, Pulse Generating Methods

included faster pulse generation, shorter duty cycles, smaller programs and more pulses were available for the control of I/O devices.

The Device Decoder board also had two 8 bit Tri-State input ports (C1,C2,D1,D2). One of these ports was used as a sense register for the RC clock, Biomation flag and the Real Time Clock (RTC) used in the sense register mode. The RC clock was used to control the rate at which some of the plotter and CRT display functions were performed.

X-Y Display Electronics

The X-Y Display (Fig. 15) consisted of four 4 bit latches (A1, A2 and B1,B2) and two 8 bit DACs. To display a point somewhere on the CRT screen, we had to specify both an X and a Y coordinate. These values (eight bit, unsigned binary) were placed in the A register and then latched into either the X or Y axis latch-DAC combination with either an OUT 6 or OUT 7 instruction. It did not matter which of the coordinates was latched out first, as long as the X data was latched with the OUT 6 instruction and the Y axis data with the OUT 7 instruction. The eight bit word, when it was latched caused varying amounts of current to be produced by the DACs. This current appeared at pin 15. This varying current caused varying voltage drops to occur across the iK resistors. These voltages were then applied to the X and Y axis deflection amplifiers of the oscilloscope via coaxial cables.

X-Y Plotter Electronics

Only two DACs were available to drive the X and Y axis of the oscilloscope and the X-Y plotter. Most of the time, the DACs were used to drive the oscilloscope. Only after the spectrum was read from the BTR were the DACs used in conjunction with the plotter. If

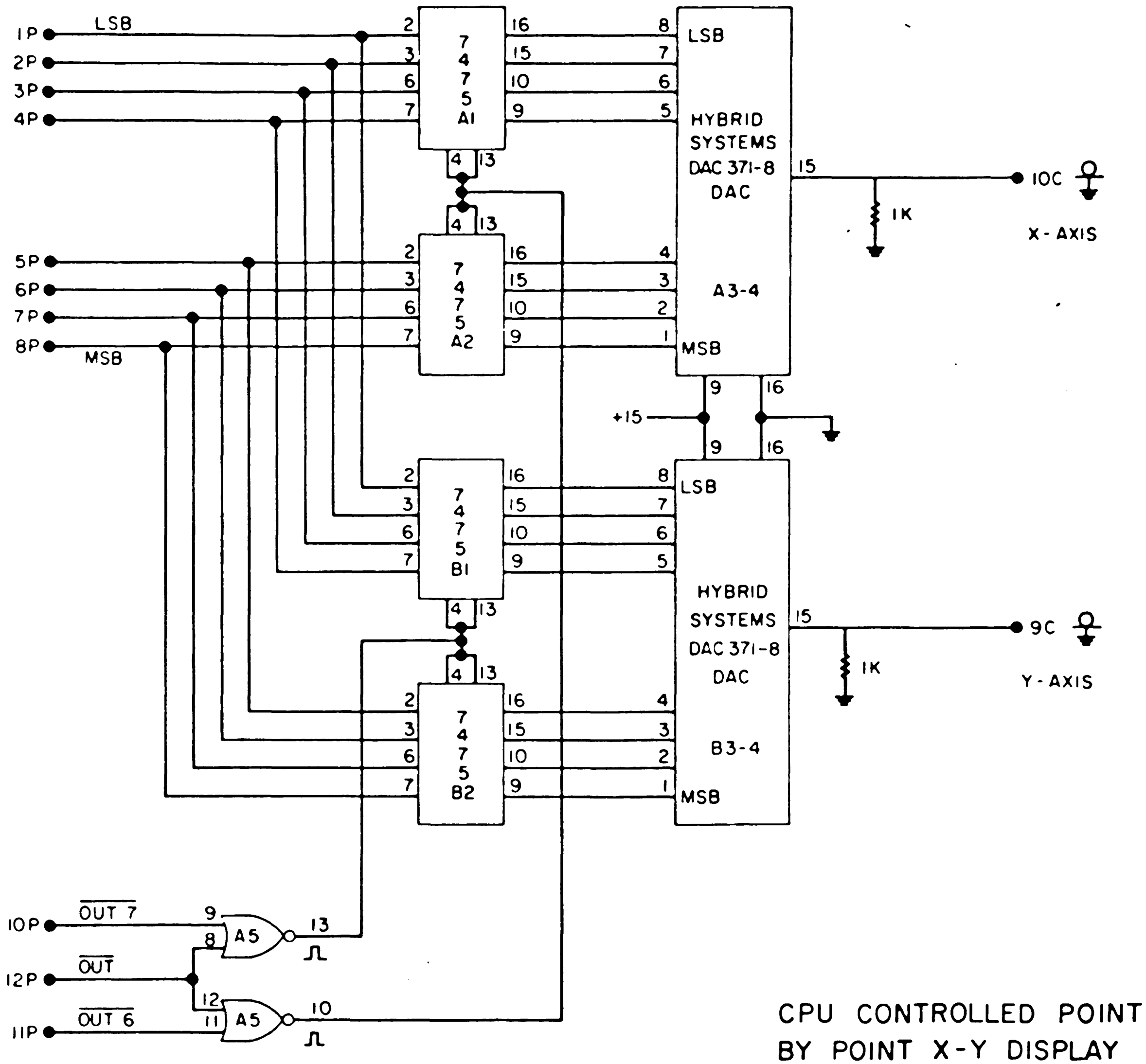

1P
2P
3P
4P
LSB
5P
6P
7P
8P
MSB
7475 A1
7475 A2
7475 B1
7475 B2
HYBRID SYSTEMS DAC 371-8 DAC
A3-4
B3-4
LSB
MSB
+15
1K
10C
X-AXIS
9C
Y-AXIS
10P
OUT 7
12P
OUT
11P
OUT 6
A5
CPU CONTROLLED POINT BY POINT X-Y DISPLAY

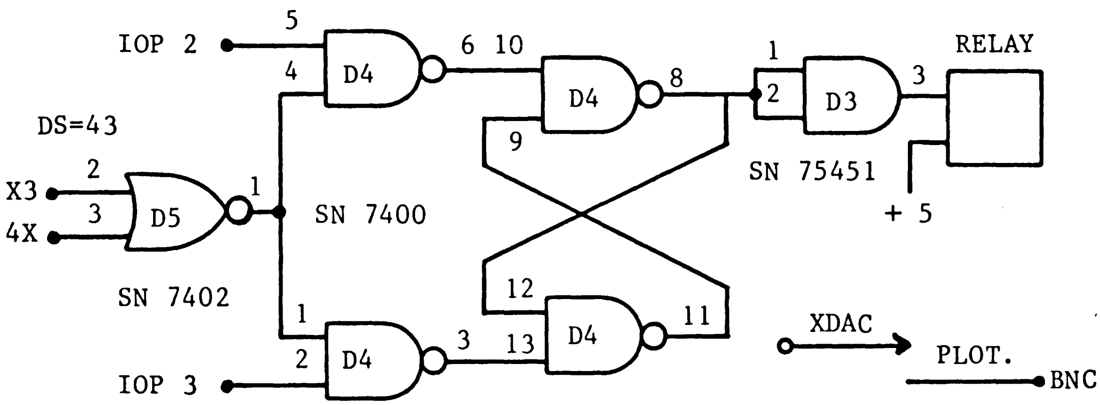
Figure 15

the DACs drove both the plotter and the oscilloscope simultaneously, the plotter would try to "follow" the display and would subsequently "chatter". To prevent chattering, an analog demultiplexer was constructed (Fig. 16) so that the analog voltages of the DACs were routed to the plotter only when the microcomputer wanted to plot data. The oscilloscope was always driven by the DACs. The demultiplexer logic consisted of the DS/IOP logic (D5, D4) required to produce two negative pulses that drove a R-S flip-flop (D4). The output of the flip-flop drove a high current driver, which sank the current that drove the DPDT relay. The contact wipers of the relay were driven by the outputs of the DACs. When the relay was energized the contacts routed the signals to the plotter.

A pen controller (Fig. 17) was also constructed so that the pen of the X-Y plotter could be lifted or set down on the plotting paper. With this, line plots or point plots could be drawn. The DS/IOP logic was the same as that used with the analog demultiplexer. The negative pulses generated by B5 and D2 were used to set or clear the R-S flip-flop (D2). The output of D2 drove the high current driver which sank the current required for opening or closing the relay contacts. The contact wiper and the N.C. contact were connected to the plotter through coaxial cable. When the contacts were open, the pen was up and when closed, down.

Real Time Clock Electronics

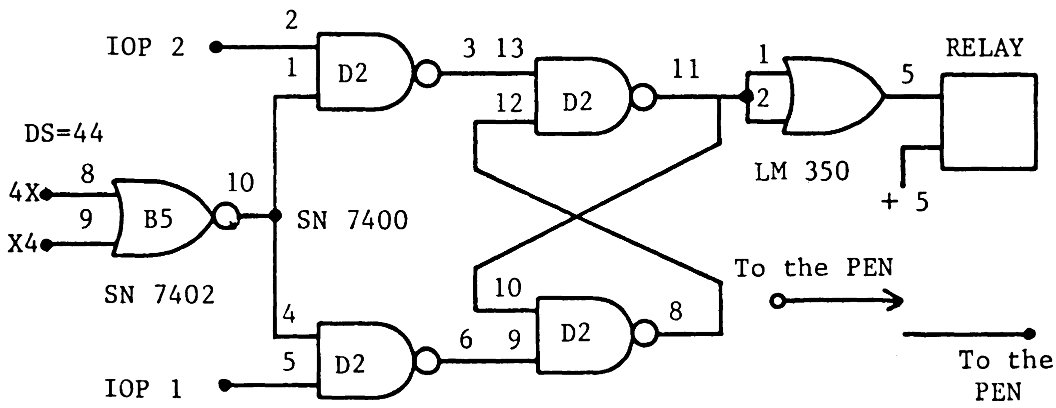
The Real Time Clock (RTC) is a hardware device (Fig.18) capable of accurately timing intervals of one to 256 seconds, in intervals of



Analog Demultiplexer for the Plotter

Slot 7

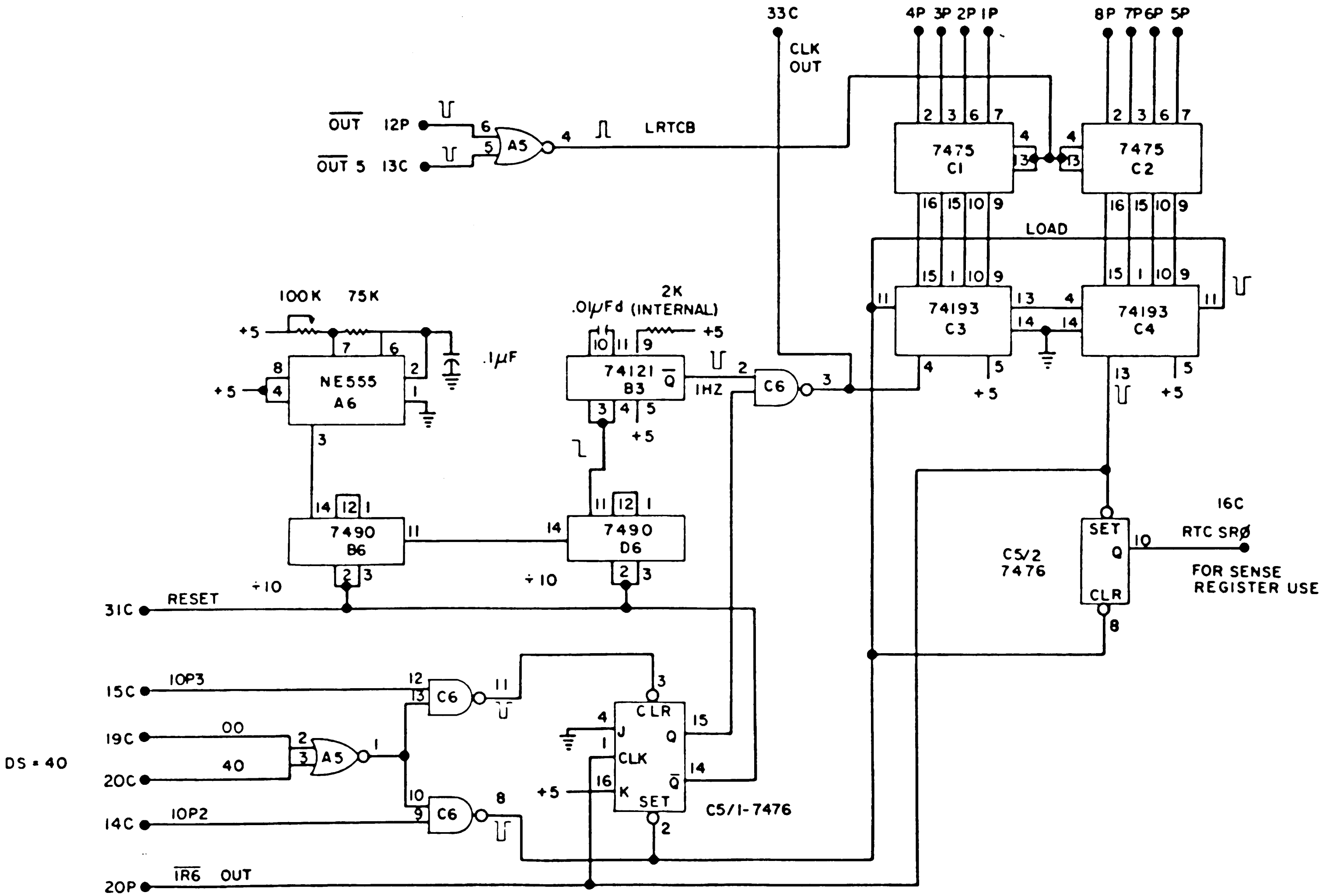
Figure 16



Pen Up/Down Control

Slot 10

Figure 17



ALL RESISTORS ARE 1/4 WATT
UNLESS OTHERWISE NOTED

PROGRAMABLE REAL TIME CLOCK

Figure 18

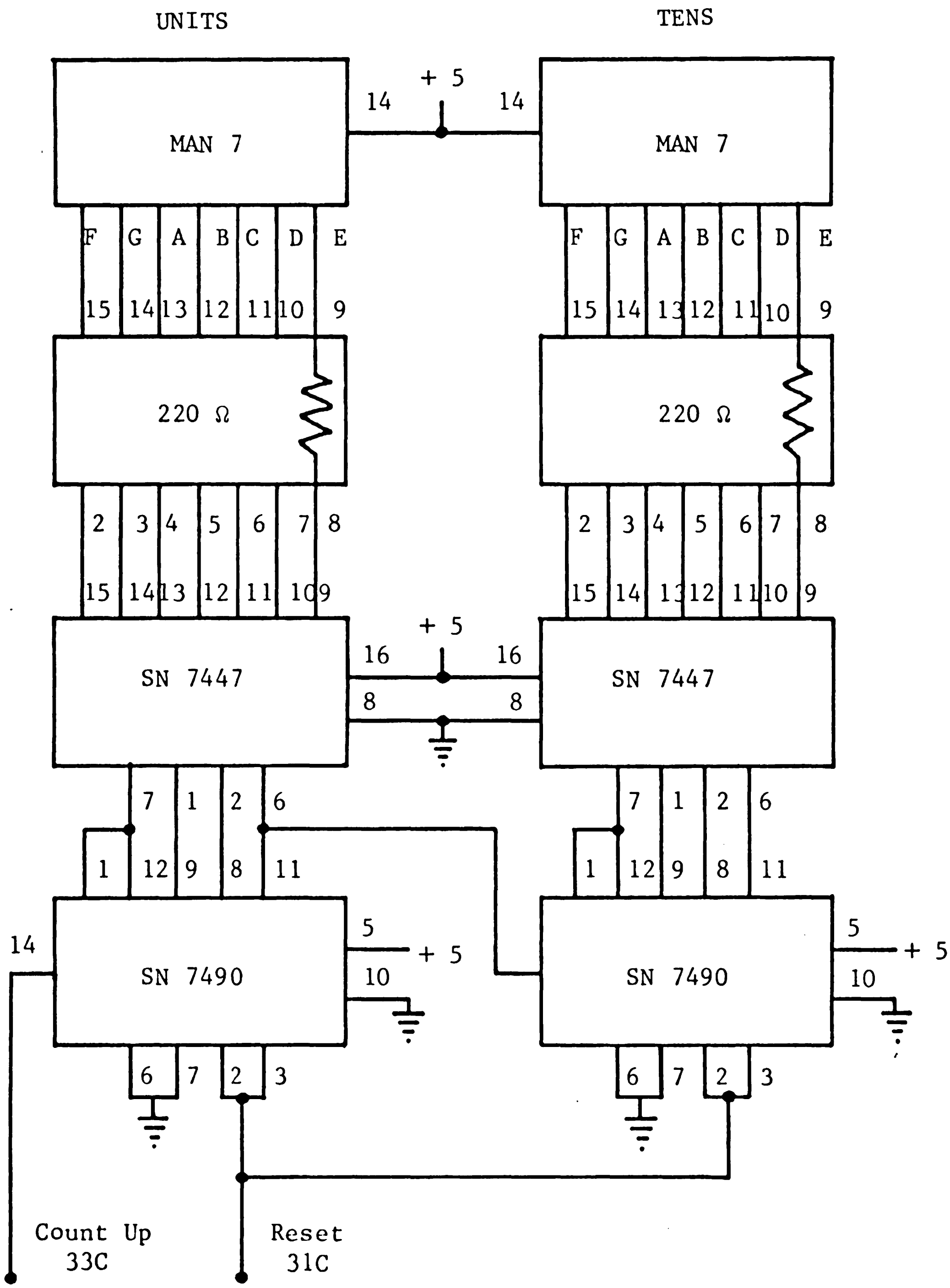
one second. This was very useful in keeping the Time Between Spectra (TBS) accurate and reproducible. As with other I/O devices, the RTC must be "programmed" by software instructions.

When a LRTCB (Load the Real Time Clock Buffer) command (OUT5) was given, the eight bit binary value stored in the A register was stored in the 7475 latches (C1, C2). When a DS40/IOP2 was generated by the CPU, the eight bit data value stored in C1, C2 was loaded into the 74193 programmable down counters, C3 and C4. At the same time, flip-flop C5/1 was set (Q to 1), which removed the reset condition from the ÷ 1000 7490 counter chain (B6, D6), and permitted the output of the 74121 One Shot (O.S.) to pulse the down counters. Each pulse into the counter caused them to count down, starting from the number previously loaded into them, until zero was reached. When zero was reached a borrow occurred (pin 13, C4) which caused C5/1 to be clocked, preventing further counting down. Flip-flop C5/1 was also set, the output of which could be used in a "sense register" I/O mode.

The first operation that the CPU performed after the RTC had timed out, was to start it again. Once this was done the CPU could perform any task requested by the user. Unfortunately, these operations take many seconds or minutes, for example in punching a paper tape or plotting spectral data. The computer had no idea how long some of these operations would take. It could not interrogate the RTC and find out how much time was left to perform a user's operation before the RTC would run out of time and require servicing again. The problem lies in the fact that the user did not want to be in the middle of a two or three minute operation when the RTC was exhausted. Since we could only sense the time out of the RTC by using software commands, it was a long time before we could get back to the sense register software and service the clock. One of the simplest solutions to this was the implementation of the Real Time Clock Display (Fig. 19).

The display counted seconds (as did the RTC) and displayed the number of seconds that had elapsed from the last servicing of the RTC. The user, knowing what value was used for the Time Between Spectra, could easily determine the number of seconds remaining before the RTC had to be serviced. Knowing this, and knowing the time required for the punch and plot routines, the user could either perform the required operations or wait until the RTC was started up again and then perform them. There were times when there was not enough time for extra punching or plotting, and this occured if a TBS of less than 15 seconds was used by the chromatographer.

The display consisted of two 7490 decade counters capable of counting from one to ninety nine. The same signal that pulsed the 74193 down counters (C3, C4) (Fig. 19), also pulsed the 7490's. Likewise, when the programmable down counters counted down to zero and the 7490 counters counted up to the value of the TBS, the 7490 counters of the display were reset as were the divide-by-one thousand (÷ 1000) counters (B6, D6).



Real Time Clock Display - Slot 16

Figure 19

SYSTEM MODIFICATIONS

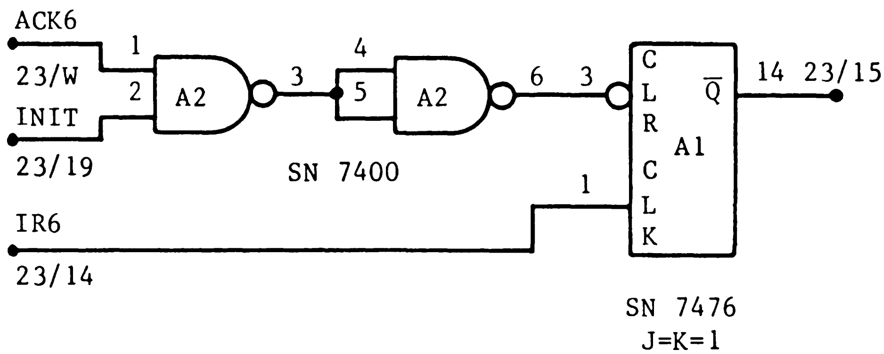
A number of problems appeared as soon as spectral data were created and the system could be fully tested. Unfortunately, most problems involved both electronic hardware and computer software (programs), making changes even more difficult.

Real Time Clock Modifications

The first problem encountered involved the sensing of the real time clock (RTC) when it had timed out. This action was initially sensed with a "sense register" (an input port). However, since data were constantly being displayed by the CPU (Fig.15), the sense register could be tested only once every 56.38 msec, the time required to display a complete 256 point spectrum. In the worst case, this could cause an error of 14.4 msec during the acquisition of 256 spectra. A greater error could occur however, if the user had typed in a valid command character on the Teletype during the actual separation. The longest operation that the user could access could take 2 to 3 minutes (punching a paper tape or plotting special data). This delay of 2 to 3 minutes in sensing the RTC could add a significant error to retention times.

Therefore, the RTC was rewired to the CPU through the interrupt hardware. With this method of sensing the RTC, a maximum error in time of 80 μsec per spectrum or an error of 0.02 secs for 256 spectra could appear, irrespective of any operation the computer was doing at the time the interrupt occurred (when the RTC timed out). As can be seen from Figure 18, when the RTC timed out, the borrow output of C4 caused A1 (Fig. 20) to be clocked by the signal IR6. This caused the IR6 line, internal to the microcomputer, to be grounded. The CPU then stopped what ever it was doing, remembered what it was doing, and then executed a specific interrupt service subroutine. Sixty nanoseconds after the interrupt line was grounded the flip-flop A1 was cleared by a signal (ACK6) which originated from the microcomputer. The interrupt service subroutine, when executed, started the RTC again, performed the dummy sweep of the PDA, did the real sweep of the PDA, stored the spectral data in memory, corrected the data with the BCC's, displayed the resulting values, punched and plotted the spectral data of interest and then went back to exactly what it was doing before the microcomputer was interrupted.

Since the interrupt facility of the 8008 CPU was always enabled (we can never cause the processor to ignore an interrupt request), problems could occur. If the computer was plotting or punching data on paper tape when an interrupt occured, when the CPU returned from the interrupt, new spectral data resided in the working current data buffer. Since the computer would continue with the task it was executing prior to the interrupt, it would continue with the plotting or punching. However, the plot or paper tape contained half the data from one spectrum and half the data from the most current spectrum. Therefore, there

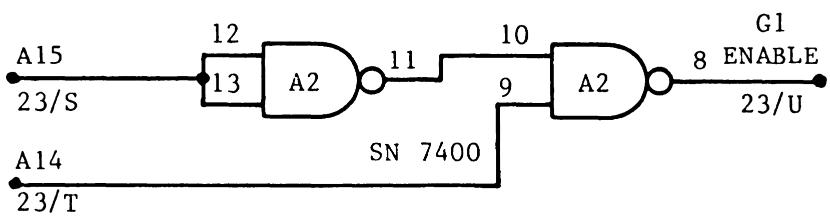


REAL TIME CLOCK

INTERRUPT LOGIC

SLOT 23

Figure 20



8008 DEVICE DECODING

(I/O) MODIFICATIONS

SLOT 23

Figure 21

had to be some way in which the interrupt facility could be disabled for a short period of time. Since the hardware could not be easily modified, the software was modified to prevent the above situation from occurring. Therefore, when ever the subroutines to plot or punch data were entered, the program modified itself, by placing an UNCONDITIONAL RETURN (007), at the very beginning of the interrupt service routine. If an interrupt occurred during this time, the RTC was still restarted, and the computer still operated in real time. But, the BTR was not serviced so that new data did not replace the data currently being plotted or punched. After the plotting or punching was finished, the actual instruction necessary for the interrupt service routine to work, was replaced in the program, by the program.

CPU Modifications

The input/output (I/O) electronics of the Control Logic microcomputer had to be altered due to a possible bus conflict during I/O operations. As wired by Control Logic, the Device Address Decoder card (LDD-503, slot 15) was active during either an input or an output operation. Since the general format of an I/O instruction is 01 RRX XX1, where the 0 is the logic level of A15 and the 1 next to it is the level of A14, the signals A15 and $\overline{A14}$ (A14 is inverted or a logic 0) are used to enable the 4:16 line decoder (SN74154). Therefore, if the user executed an OUT instruction and had two Output ports with addresses that differed by 8 (decimal), both output ports would latch the same data. There were three groups of eight output ports, therefore, the electronics did not distinguish between the banks of eight ports. To remedy this, the electronics of Figure 21 were added to a wirewrap card in the CPU. A number of signals had to be rerouted, as can be seen in Table 2.

X-Y Display Modifications

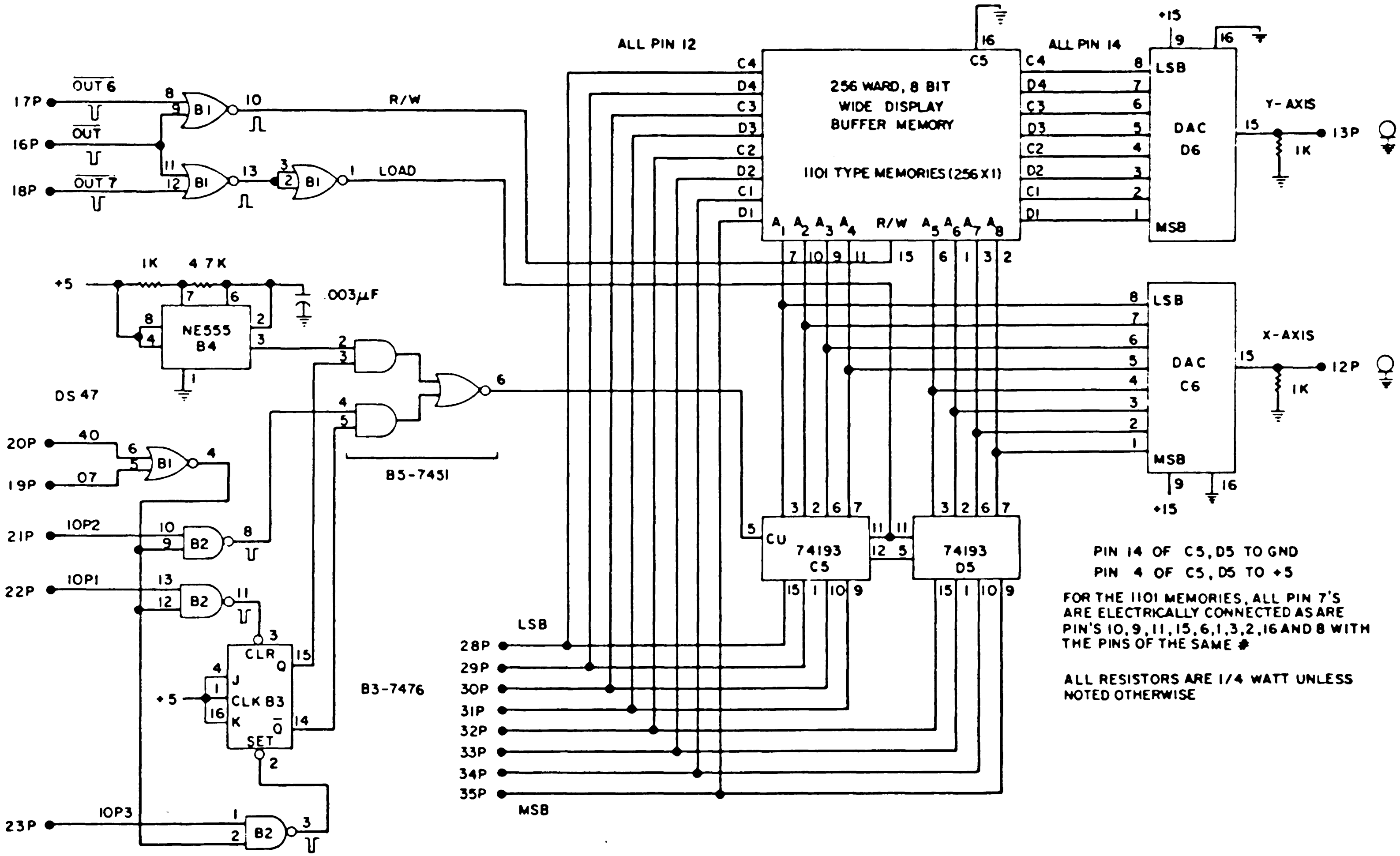
As the computer began to control more electronics associated with the detector and execute larger and larger subroutines in the computer software, there was less time for the computer to perform specially requested user commands. For this reason, the computer was relieved of the task of displaying data on the oscilloscope.

TABLE 2

CPU DEVICE DECODER MODIFICATIONS

Break	Signal	Connection
	A14N	11/11 to 15/10
	A15	11/13 to 15/K
Make		
	A13	11/T to 15/10
	A14	11/20 to 23/T
	A15	11/13 to 23/S
	Enable	19/U to 15/K

When the spectral data were finally stored in the computer's memory (after being read from the BTR), a short subroutine loaded the spectral data out to the Display Controller (Fig. 22). Once this was done, in 51.64 msec, the computer was free to perform any task requested by the user. Previously, the computer did all other



DISPLAY CONTROLLER

Figure 22

tasks before entering the CRT display routines. If the computer was busy enough and the Time Between Spectra was short, the spectral data might not be displayed at all.

To load the Display Controller with up to 256 data points, a DS47, IOP1 would first have to be issued (executed) by the CPU. This would cause B3 to be cleared, with Q going to a 0. This locked out the NE555 (B4) clock output from continuously updating the buffer memory address register (counters D5 & C5). The A register of the microcomputer was then set to 000, and an OUT 7 issued. The 000 data value was latched into the SN74193 programmable counters C5 and D5, effectively setting the buffer memory address to 000. With the H&L registers of the microcomputer properly set up to point to the spectral data stored in the microcomputer's memory, the data values were fetched from memory into the A register. An OUT 6 was executed, which wrote the data value in A into the Display Controller's memory. The OUT 6 actually pulsed the R/W lines of all eight memory integrated circuits. When the write command was executed, the data was loaded into the memory location addressed by C5 and D5. When the data had been written into the memory, it appeared at the output of the memory in a few hundred nanoseconds. The data appearing at the outputs of the memory caused an analog voltage to be produced via the Digital-to-Analog Converter D6. After the data was written into the Display Controller, the CPU memory pointers were increased by one, and an IOP2 issued. The DS 47 did not have to be reissued because of the latches on the device decoder card. The IOP2 instruction caused the memory address counters to be incremented by one. The next successive data value were retrieved from the computer's memory and written into the buffer memory. When the display controller's memory had been filled, the actual display of data could be initiated by having the CPU issue an IOP3. This sets B3, causing the Q output of B3 to go to a logic 1. This permitted the clock pulses of the NE555 to reach the SN74193 counters, which caused the memory address to be continuously increased by one. This caused a ramp to be produced by C6, which went to the X-Axis of the oscilloscope. As the memory address was continuously updated, new data values appeared at the output of the buffer memory, causing the output of D6 to vary. This new analog voltage fed the Y-Axis of the oscilloscope. The process continued until the CPU issued another DS47/IOP1. The NE555 (B4) was set to a frequency of about 60 KHz. This means that the display controller put out one point, both X and Y coordinates, every 16.6 μsec. A complete 256 point spectrum was displayed once every 4.2 msecs, or 13 times faster than the CPU controlled display.

Since only two DACs were available, they also had to be used to drive the X-Y plotter. To plot data, the X-Axis coordinate was latched into the 74193 counters (B5, C5). This caused the analog voltage output of the X-Axis DAC to change. The Y-Axis data value was then written into the display buffer memory. The address was irrelevant, but was the X coordinate. When the data value was written into the memory, it immediately appeared at the eight outputs of the memory, causing an analog voltage to be produced by the Y-Axis DAC. At the end of the plot, the contents of various memory locations in the display controller's memory were altered. Rather than having the computer keep track of which memory locations had been altered and changing only a few select locations, it was easier to rewrite the old spectral data back into the display controller's memory completely.

Linear Array Clock Modifications

Further work with the system indicated that there were still problems associated with using a PDA. There appeared to be a significant decrease in the video output amplitude when run in the External mode (where the CPU provided the trigger pulse and the BTR provided the clock pulse train) compared to the Internal mode of operation (where the PDA logic provided its own clock and trigger signals). Basically, the internal clock appeared to produce a larger video output than the external clock, even though the two clocks were of the same frequency. The problem appeared to be due to the duty cycle (ratio of times of the logic 0 and logic 1 states) of the external clock. Since the PDA is a MOS (Metal-Oxide-Semiconductor) device, the clock duty cycle determined how long a time was used to transfer the charge of one capacitor to the adjacent capacitor. If too long a transfer time was used, the results were slurred, with a concomitant attenuation of the video signal. In digital MOS devices (the PDA is an analog device), slurring appears as a loss of data (logic 1 to a logic 0). This problem was solved by using the BTR clock to pulse a One Shot (Fig. 12). The negative portion of the clock pulse was reduced to 150 nsec, resulting in a larger video output.

Optical Modifications

When initially conceived, the LC detector system was to be designed from a general purpose, rapid scanning, UV-VIS spectrometer system. The spectrometer system was initially designed for stopped flow kinetic studies. It was hoped, that by simply connecting the column effluent port from the liquid chromatograph or from the single wavelength detector, to the stopped flow detector cell, the study could be begun. However, the dead volume of the cell and its associated large bore tubing precluded its use in this study. Therefore, the Aminco stopped flow cell was replaced with a Chromatronix (Spectra-Physics) 1 cm dual path quartz cell. This was mounted on a ball joint attached to the optical bench to permit three dimensional movement in adjusting the cell's position. When the cell was mounted vertically, the light path was not horizontal. However, the ball joint permitted the cell to be tipped over, making the light path horizontal, as required by the rest of the optical system.

During a portion of this work, a zirconium arc lamp (Sylvania C-25) was used as a light source for the spectrometer. The lamps were good point sources, but they were difficult to start, they had short life times, sometimes less than 15 hours, they were expensive, and difficult to obtain. Both a tungston and a quartz-halogen lamp were used as substitutes. Because of its high output, 55 watts conpared to 18 watts, the quartz-halogen lamp was preferred over the tungston lamp.

COMPUTER SOFTWARE

All of the computer programs for the multiwavelength detector system were in assembly language. They were prepared on a Digital Equipment Corporation (DEC) PDP-8/L, I or M using DEC's Disk Monitor System (DF32) or OS/8. A double precision multiply/divide math package (Intel # 8-9, 8-12) was used to correct the spectral data for the detector's responsivity. A special loader was written and programed into EAPROM so that the paper tapes with PAL8 format could be read directly into R/W memory. The third pass listings of the loader and the Detector Operating System/Executive (DOS/EXEC) along with flow diagrams for the more important subroutines can be seen in Appendices A, B, C and D. The DOS/EXEC program was always loaded, run and debugged in R/W memory. The programs were debugged in their early stages of development by OPERATE, a program developed within the Research Group by R.E. Dessy and J.A. Titus (57).

The computer programs were responsible for acquiring, processing and presenting the data to the user. The programs provided the proper pulses for controlling the linear photodiode array and the transient recorder. Only when the computer software detected the end of the 256 point digitization were the data words transferred from the transient recorder's memory to the computer's memory. The spectral data were then corrected by multiply and divide routines for the non-linear responsivity of the detector. The data values corresponding to the array numbers selected by the user were then plotted and punched on paper tape. Lastly, the display controller's memory buffer was loaded with the 256 point transmittance spectra and was then started.

The program just described is essentially the DOS. When the DOS was operating, the computer took care of all the data acquisition, reduction and data output. Therefore, during a simple separation, little if any intervention by the user was required. The EXEC had a completely different function. It was used to get the system started and calibrated using commands typed on the Teletype. The Baseline Correction Constants (BCC) used for correcting the spectral data for the responsivity of the linear photodiode array (PDA) were determined by the EXEC. The BCC had to be determined before the user used the DOS. A cursor-driven CRT display can also be called by the EXEC and was used for determining the arrays to monitor when a mixture of components was to be separated. The point and line plot routines could also be used and the data residing from 7400 through 1177 (017 000 - 023 377) could be plotted with either routine.

The starting address of the EXEC was 2400 (005 000). Since the DOS can and usually is started by a keyboard command when the EXEC is operating, the entire system was started by jumping to memory location 2400. The Teletype keys that were active (recognized) by the EXEC and their meanings can be seen in Table 3.

TABLE 3

EXEC COMMAND SUMMARY

B BOX Draw the coordinate axis with the tic marks.

C CALIBRATE Get a pure solvent spectrum, calculate the BCC, multiply the spectral data by the BCC and display the results. The multiplication and display of the results should be a straight line, giving a visual check of proper system operation.

G GET Get a spectrum and display the raw data.

K KILL Set the 256 dark current values to 0.

O POINT Point plot the contents of the working data buffer (7400 - 7777; 017 000 - 017 377).

P LINE Line plot the contents of the working data buffer.

R REPEAT This key may only be used after the DOS has been used. It assumes that the TBS, ITEG and array numbers of interest have already been stored in memory. When the R key is pressed, the EXEC exits to the beginning of the actual data acquisition portion of the DOS. The microcomputer will still wait for the user to press any Teletype key before the actual data acquisition process is repeated. This key is used if more than 256 spectra are required for a separation. It gives the user time to switch the X-Y plotter paper and then get back to the data acquisition portion of the DOS.

S SCALE Scale the raw data by the BCC and display the results. The BCC must have been previously determined.

X CURSOR Enter the cursor routine so that the array numbers

TABLE 3

EXEC COMMAND SUMMARY (cont.)

to monitor during the separation can be determined.

Z DOS Enter the DOS. The ASCII header paper tape must be in the Teletype's paper tape reader and the selector switch set to ON before this key is pressed.

1,2 or 3 DATA Get the data from one of three buffers and put it into the working buffer. When in the working buffer, the data may be scaled and displayed, plotted or punched onto paper tape.

D OPERATE Return to OPERATE. This key is used when either the DOS or the EXEC are to be debugged or changed.

When the user is ready to begin a separation, the Z key is pressed when the EXEC program is operating. When this is done, the ASCII header tape in the Teletype paper tape reader is read into the computer and the user establishes the operating parameters of the separation.

```
TBS:  20
ITEG. TIME: 7
ARE ARRAY #'S KNOWN ? NO35,132,224,
PLOTTER ON !
CALIBRATE THE PLOTTER: OXOXOXOYOYOYOG
PUNCH ON !!!!!
ARE YOU READY ? #@O@C@
```

TYPICAL COMPUTER PRINTOUT

The TBS represents the Time Between (successive) Spectra, in seconds. This number may be between one and 99 seconds (integer values only). This is the time that is loaded into the Real Time Clock and is the time that the microcomputer waits before sweeping out the linear photodiode array.

The ITEG is the integration time in milliseconds and is the delay time between the dummy sweep of the array (used to recharge the capacitors) and the real sweep out of the spectral data that will eventually reside in the computer's memory.

The answer to the question "ARE THE ARRAY #'S KNOWN ?" may be

Y for yes or N for no. The answer is determined by whether the user has done the separation before or not. If the separation has been done before, the user answers "Y" and then the previously determined array numbers (if they prove to be experimentally satisfactory) are then typed into the microcomputer. After the last array number is typed in, the RETURN key should be pressed and the microcomputer will then enter the plotter calibration routines. If the answer is "N", the DOS will enter a special detector service routine. The user then places either pure samples of the compounds to be separated or a mixture to be separated into the detector cell. After the sample is in the cell, the user can acquire transmittance spectra and drive the blinking cursor along the spectrum using six Teletype keys.

The F key (FORWARD) moves the cursor right by one array position on the CRT screen. The B key (BACKWARD) moves the cursor left by one array position on the CRT screen. When the cursor has been positioned on an array number (wavelength) characteristic of one compound, the S key (SAVE) can be used to save the array number in the microcomputer's memory. Using the S key, up to eight array numbers may be saved. Whenever the S key is pressed, the array number is also printed out on the Teletype for future reference. This is useful if the separation is to be performed again.

The C key (CONTINUE) causes the cursor to move from left to right across the CRT face. The speed and blinking rate of the cursor is determined by the setting of the RC clock. The cursor will continue its movement until the F, B, S, X, N or T key is touched. The N key

(NEXT) causes a new 256 point spectrum to be acquired, scaled and displayed on the CRT. The cursor is then restarted and the microcomputer then waits for any user commands. The N key is useful if the user has many samples from which one or two characteristic array numbers are to be determined. When the user wants to return to the DOS or the EXEC, the X key (EXIT) is pressed. If the user was in the DOS, the program would begin the plotter/CRT calibration routines.

The T key (TRANSMITTANCE) is pressed when the transmittance of the sample at a particular array number (wavelength) is desired. When the T key is pressed, the array number where the cursor presently resides, along with the "transmittance" at that array number, is typed out. In actuality, the number printed out as the transmittance must be divided by 250 and then multiplied by 100% to obtain the true transmittance value.

If the user has pure samples as references, the cursor can be used to select up to eight array numbers characteristic of the pure samples. After one sample had been scanned and the characteristic array numbers determined, the detector cell should be flushed with pure solvent and the next sample introduced. After this, the N key is pressed, and the array number determinations continued. If no pure samples of the material to be separated are available, the mixture should be injected into the detector, and the array numbers to be monitored spread over the spectrum in areas of strong absorbance. This is certainly not as exact as the pure sample method, but it may be the technique most often used, particularly when the separations are not repetitive or routine.

After the array numbers are determined, the plotter/CRT calibration routines are entered if the user is in the DOS. The calibration routines cause the maximum analog voltages (deflections) from the DAC's to be produced. The gain and zero points of both the plotter and CRT can then be established.

The Teletype again plays an integral role in this portion of the DOS. The X, Y, O, G and S keys are the only keys recognized by the software; all other keys are ignored. The O key causes the plotter pen and the CRT beam to go to the origin established by the user by producing 0 volts from both the X and Y axis DACs. The X and Y keys cause the maximum X and Y voltages to be produced while the voltage of the other axis is 0.

TABLE 4

VOLTAGES PRODUCED BY THE X, Y AND O KEYS

KEY	X VOLTAGE	Y VOLTAGE
X	MAXIMUM	0
Y	0	MAXIMUM
0	0	0

When the plotter and CRT amplifier gains have been suitably adjusted, the G (GO) key will cause a coordinate axis (a rectangle) to be drawn, with the X axis divided into five sections by tick marks. The speed at which the coordinate axis and tick marks are drawn is determined by the RC clock. The S (SKIP) key is used only for diagnostic purposes and causes the actual plotting to be skipped, although the CRT and plotter can still be calibrated before the S key is pressed.

When the plotting is finished, the microcomputer informs the user to turn on the Teletype paper tape punch. This enables the user to get a punched paper tape of any plotted data. When turned on, the computer will punch the TBS and the array numbers selected by the user on the tape. The TBS is punched first, then the array numbers followed by a 0 terminator. These data are punched as single-word binary numbers. After these data have been punched on the paper tape, the microcomputer waits for the user to press any printing Teletype key. This causes the data acquisition portion of the DOS to begin operation. Normally, the user would inject the sample to be separated and press a Teletype key at the same time. During the data acquisition portion of the DOS a number of Teletype keys are also active, including the Q, O, P, S, I and N keys. The actions caused by these keys are summarized in Table 5.

Since the punch is on during the entire data-acquisition sequence, none of the user selected operations noted in Table are echoed on the Teletype printer. When the user touchs a Teletype key to begin data acquisition, a specific sequence of events takes place. This sequence is the same when the RTC times out. These operations can be seen in Table 6.

TABLE 5

DATA ACQUISITION COMMAND SUMMARY

Q	QUIT	Stop the RTC, go to the EXEC.
O	POINT PLOT	Point-plot the current spectral data.
P	LINE PLOT	Line-plot the current spectral data.
S	SAVE	Save the current spectral data in one of three buffer areas. The area pointer is initially set to one and is not incremented after a spectrum is saved. This way, we can save the best spectrum.
I	INCREMENT	Increment the data buffer pointer.

TABLE 6

DATA ACQUISITION OPERATIONS SUMMARY

1) Load the RTC and start it.

2) Get the spectral data from the PDA into the microcomputer. This includes the dummy and actual sweep outs of the PDA, the arming and triggering of the BTR and the moving of the spectral data from the memory of the BTR to the microcomputer's memory.

3) Correct the data with the BCC. This corrects the data for the responsivity of the PDA.

4) Find the transmittance values for the user selected array numbers.

5) Plot out the data from the user selected array numbers.

6) Punch the same data on to paper tape.

7) Display the 256 point spectrum on the CRT.

8) Monitor the Teletype for any user commands and wait for the RTC to time out. When the RTC does time out, proceed to step 1.

CHARACTERIZING THE DETECTOR

One of the first observations made when using the detector was that the video output signal was noisy. Attempts were made to reduce this noise by inserting an RC filter bewteen the output of the PDA and the input of the BTR. With this filter, as with any other filter, the amplitude of the noise should have been attenuated more than the amplitude of the video (data) signal. Also, the phase distortion of the signal should have been as small as possible. Unfortunately, this type of filter was only marginally effective in reducing the noise of the video signal.

One of the obvious applications of the microprocessor would have been to have it perform a digital filtration of the data. However, the greatest pitfall to implementing this would have been the amount of time it required. The 8008 CPU executes an instruction in 20 to 60 μsec, while a PDP-8 executes instructions in 1.5 to 4.5 μsec. Therefore, in performing operations, the PDP-8 is at least 13 times faster than the 8008. Nevertheless, a simple signal averager was written and implemented on the microprocessor. It consisted of taking 16 spectra, adding all the data values together that were associated with one array number and dividing the sum by 16. Actually, all 16 spectra were not acquired and stored in memory at one time, because it would have required 4,096 memory locations to store this much information. Instead, one spectrum was taken and then added to the previous spectral sum. After all 16 spectra were added, the data values were divided by 16 and then the results were stored in memory. Using this method, only 512 memory locations were required to store the running sum and finally, the average. By using this method of signal averaging, the signal-to-noise ratio (S/N) should have increased by the $\sqrt{N}$, where the N represents the number of spectra acquired. In the case of 16 spectra, the signal to noise ratio should have increased by a factor of four. However, when the signal averager was used, there appeared to be little improvement in the quality of the spectral data. To verify that the program was operating properly, the same data were used in a signal averaging program written on and for a PDP-11/03 (LSI-11). This processor has floating point firmware (floating point mathematical operations are carried out by a combination of hardware (electronics) and software (programs)) and therefore is more accurate in its calculations than the double precision (16 bit) multiply-and-divide routines used by the 8008 microcomputer system. As with the 8008, there was little improvement in the quality of the spectral data when the signal averager was run on the PDP-11. This general type of signal averager program is designed to eliminate or reduce the effect of random noise in the spectral data, based on the assumption that over a number of spectra, there will be about the same number of positive and negative excursions of the video signal due to noise. Therefore, they should average out to zero. Since there was very little improvement in the signal after averaging, there must not have been much random noise in the video signal from the PDA in the first place. Another type of noise that might have been present was systematic noise. This type of noise, since it is systematic, cannot be removed with a simple signal averager. Horlick reorted (26) that a sinusoidal wave may be imposed on the video output of the array, with a frequency of one quarter the clock rate. This type of noise was not seen in the dark current (no light striking the array) plot of Fig. 23.

Since the use of a linear photodiode arrat for chemical analysis is fairly new, attempts were made to characterize the array in terms of sensitivity and responsivity. This work was done when the spectrometer had a bandwidth of 172 nm. Therefore, it could resolve 0.6 nm. To determine the dark current associated with the array, power was applied to the array, but the light source was not turned on. A single scan of the array dark current may be seen in Fig. 23. Unfortunately, the dark current also varies with time. A plot of responsivity as a function of wavelength for the silicon detector is also shown in Fig. 23.

To test the sensitivity and responsivity of the detector, standard solutions of azobenzene in hexanes (0.1% IPA) were used. An aliquot of one of the standard solutions was placed in the detector cell and a spectrum obtained. The combined results can be seen in the plots in Fig. 24. A plot of absorbance versus concentration

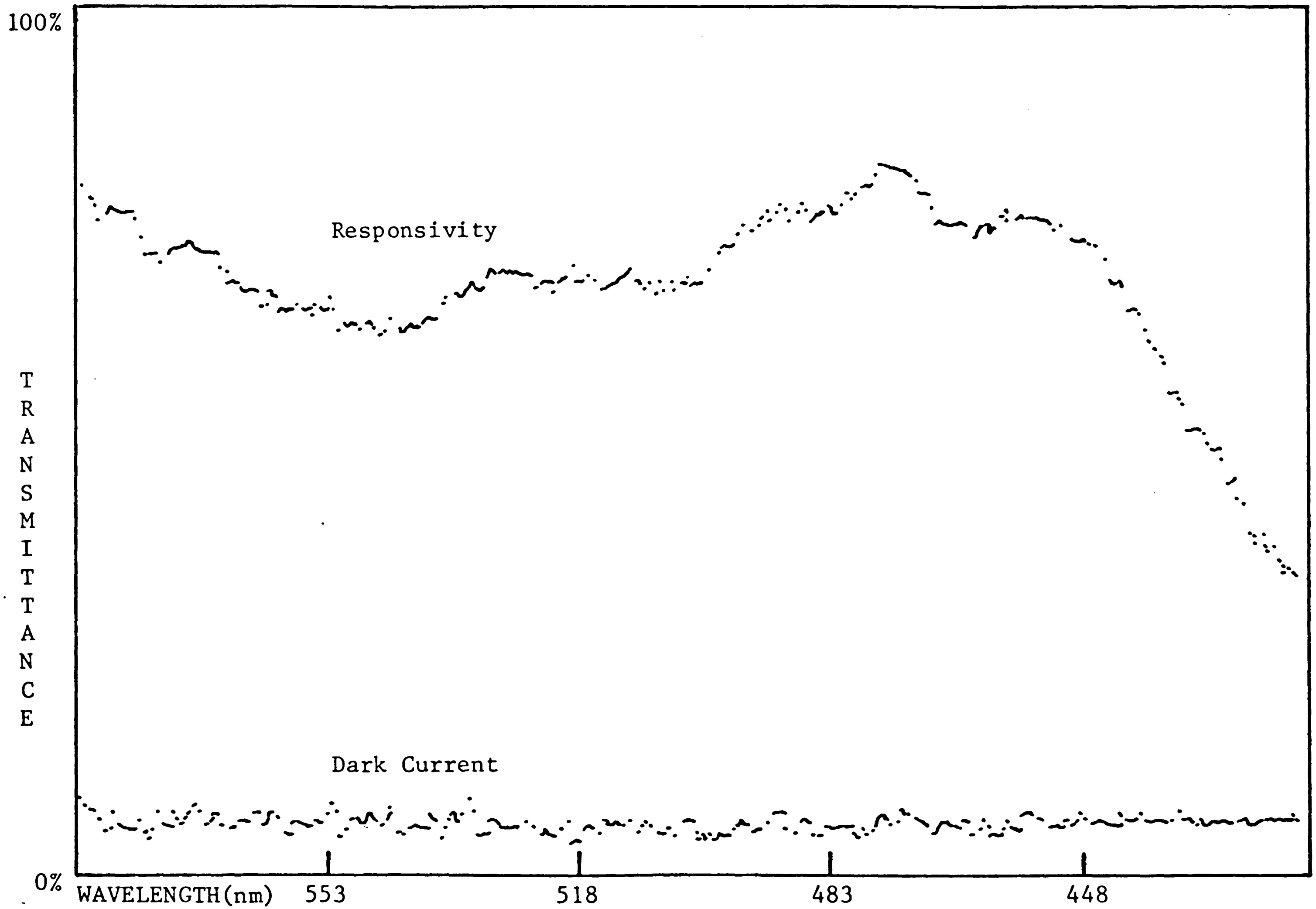


Figure 23 Transmittance versus Wavelength Plots of Dark Current and Responsivity for the Photodiode Array

Spectral Conditions

Sweep Frequency - 50 KHz

Integration Time - 7 msec

Biomation Scale - 2 V full scale

Azobenzene in hexanes (0.1% IPA), concentrations of:

1) 1.05×10^{-5} M

2) 1.05×10^{-4} M

3) 2.64×10^{-4} M

4) 5.27×10^{-4} M

5) 1.05×10^{-3} M

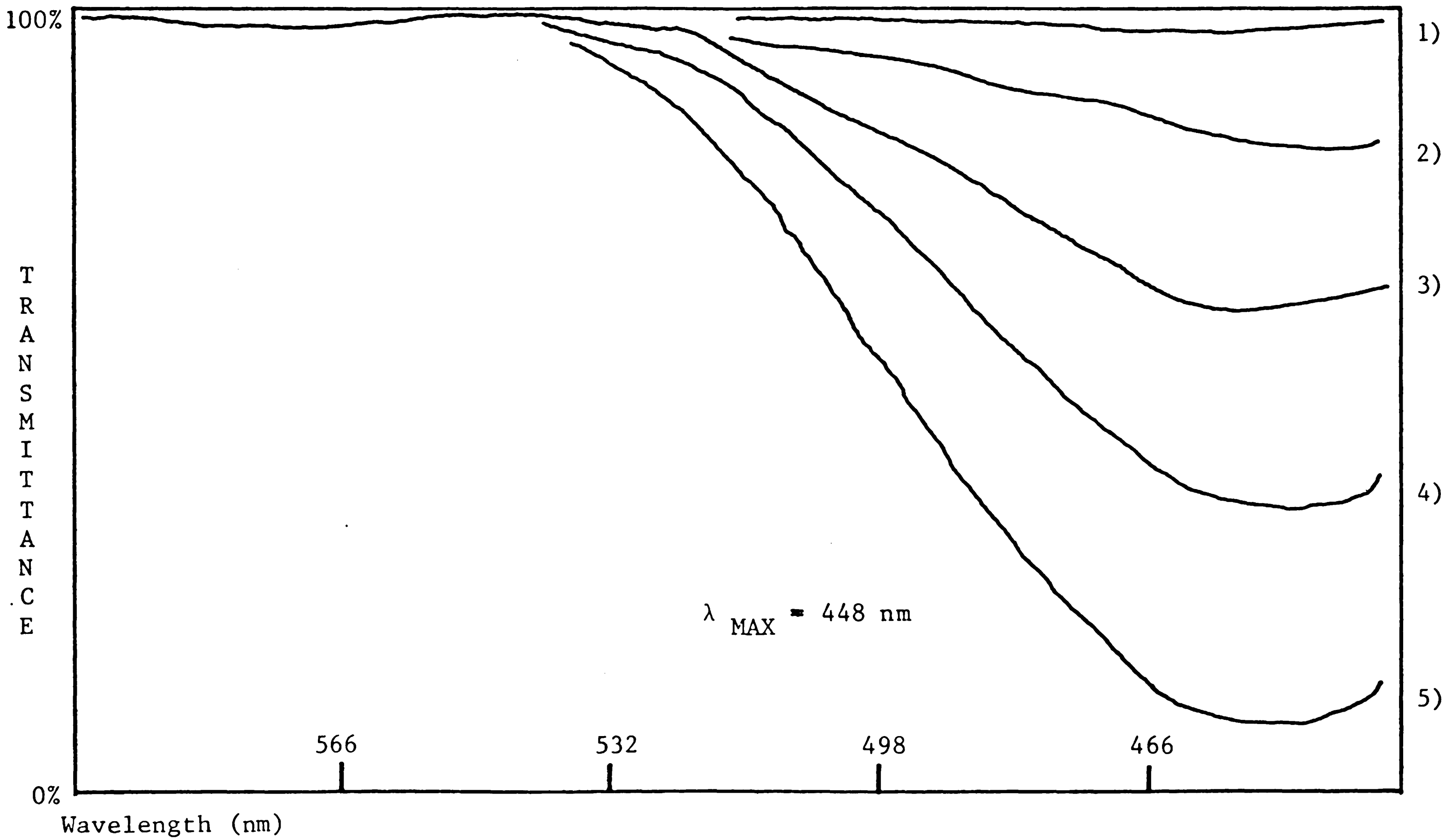


Figure 24 Plot of Transmittance versus Wavelength for varying concentrations of Azobenzene solutions

(Fig. 25) is reasonably linear, with the least concentrated solution having an absorbance of 9 milliabsorbance units. Note that the plotted spectra have been corrected for the responsivity of the detector and that the dark current has not been subtracted from the raw data.

To examine the effect of integration time on the quality of acquired spectra, an aqueous solution of neodymium magnesium nitrate {2 $Nd(NO_3)_3 \cdot 3\ Mg(NO_3)_2$} was prepared and placed in the detector cell. The changes in the integration time were made through software and the sweep-out frequencies were changed by switching the frequency of the BTR.

When looking at Fig. 26,27,28 and 29, the following should be remembered: If the array is completely charged (no light striking it), the sample must absorb all of the visible light. If this happens, the computer plot will be a straight line on the lower portion of the coordinate axis. If the array becomes completely discharged, then the sample absorbed none of the visible light and the computer plot will be at the top of the coordinate system. Therefore, the spectra presented are all transmittance spectra.

By varying the integration time, the time that the light struck the array was varied electronically. With an integration time of one msec, the array had little time to discharge, and the lowest trace in Fig. 26 was produced. As the integration time was increased, the PDA was discharged more and more, producing transmittance signals that were larger and larger. Note that as the integration

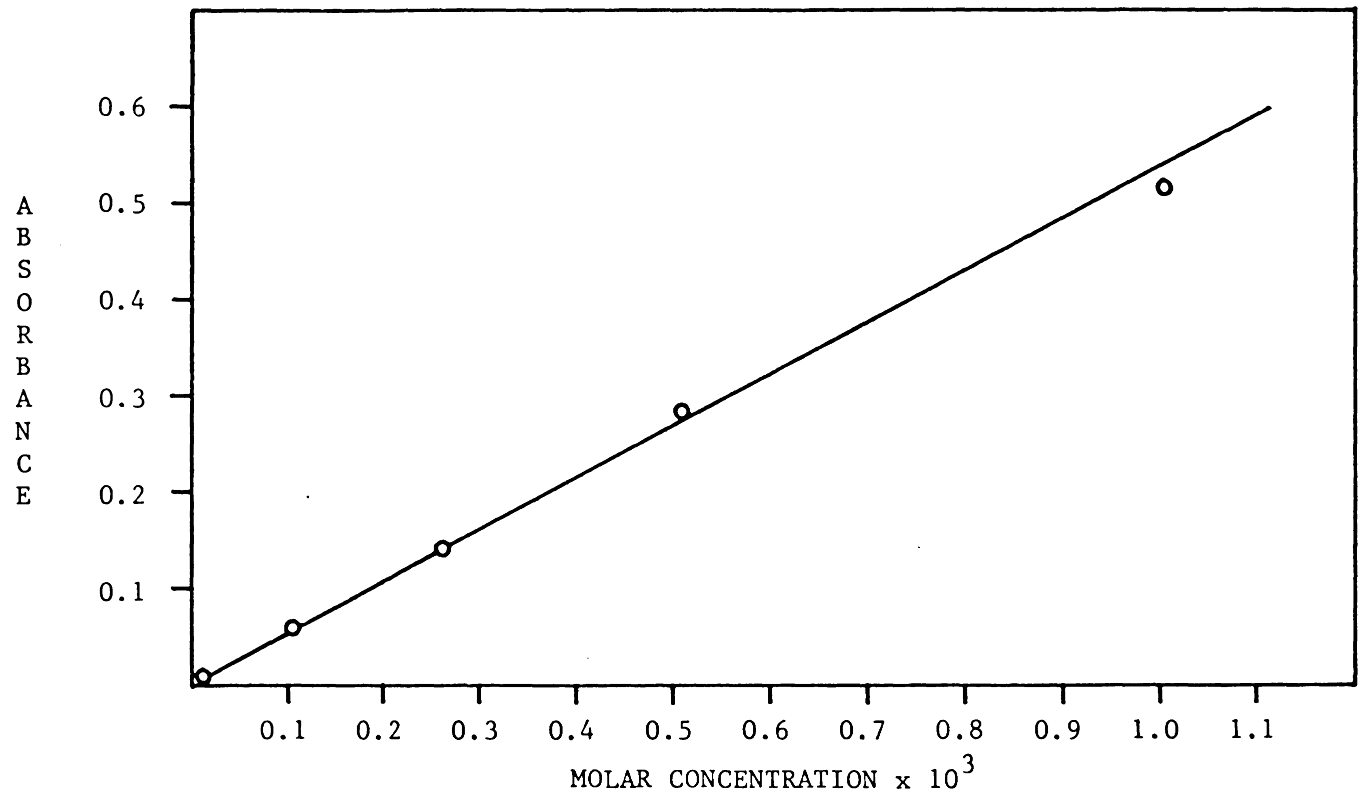


Figure 25 Plot of Absorbance versus Concentration for Azobenzene solutions

Spectral Conditions

Sweep Frequency	-	500 KHz
Biomation Scale	-	2 V full scale

Aqueous neodymium magnesium nitrate solution

Integration Times (msec)

1) 8

2) 6

3) 4

4) 3

5) 2

6) 1

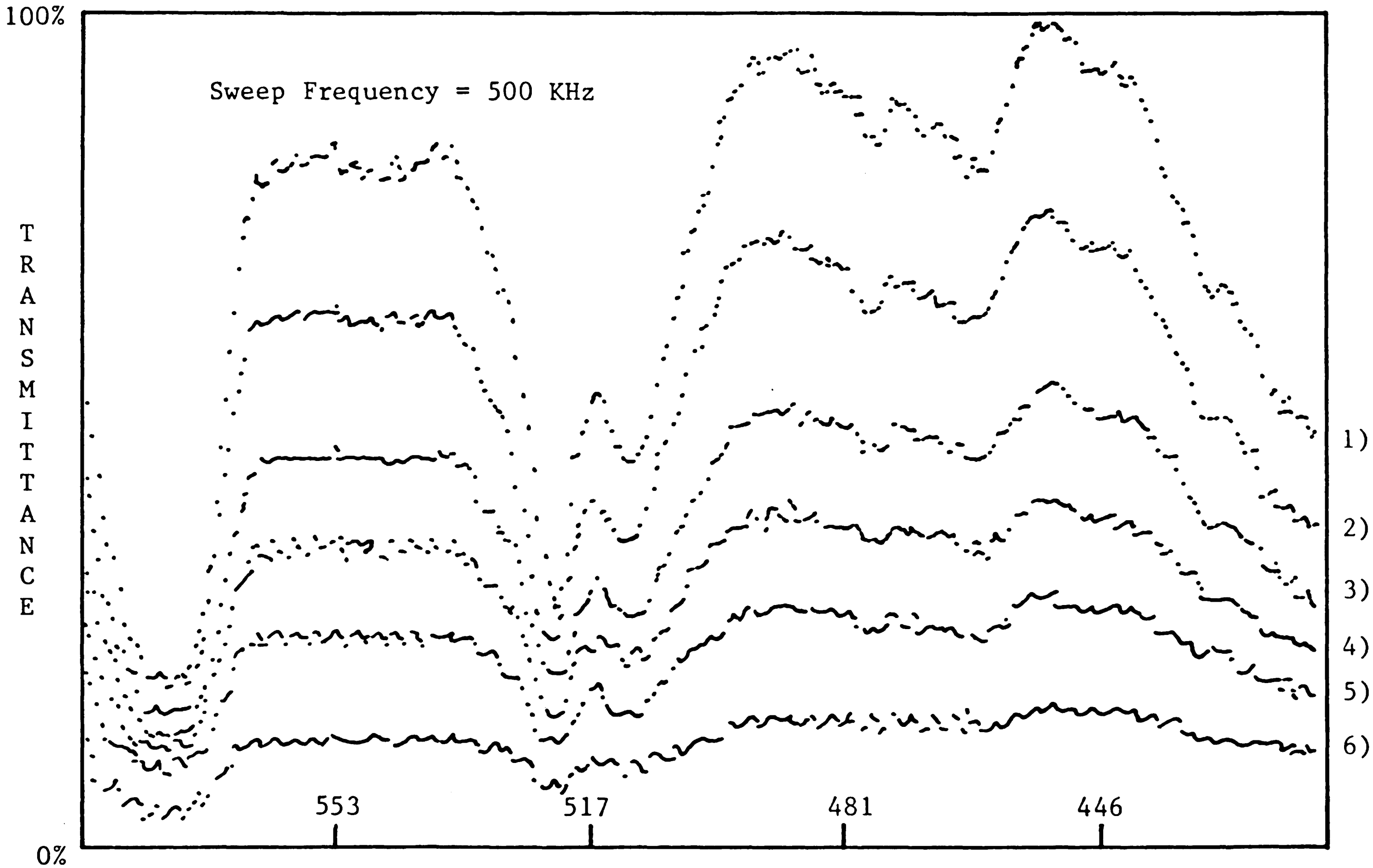


Figure 26 Plot of Transmittance versus Wavelength for neodymium magnesium nitrate at varying integration times

Wavelength (nm)

time increased, the peaks at 475, 468 and 460 nm began to become more distinguishable from the baseline. Also note the appearance of the shoulder on the lefthand side of the peak at 522 nm. A spectrum acquired with an integration time of 7 msec may be seen in Fig. 27. Dark current was not subtracted from any of these spectra, and only the spectra of Fig. 27 and 29 were corrected for the responsivity of the silicon PDA. The spectra in Fig. 30 show the effect of correcting the spectral data for the responsivity of the silicon linear photodiode array.

By lowering the sweep time by a factor of ten and then varying the integration time, the spectra of Fig. 28 were produced. As with the spectra produced at a sweep frequency of 500 KHz, the quality of the spectra taken at the 50 KHz sweep rate improved as the integration time was increased. In neither Fig. 26 or Fig. 28 were plots made when the integration time was too long. If the integration time was too long the arrays were completely discharged. A plot of this then contained elements that were completely flat at the top of the coordinate system. A spectrum was also produced with an integration time of 7 msec at a 50 KHz sweep frequency, Fig. 29. Note the peaks at 454, 432 and 428 nm. This spectrum is very similar to one produced by a commercial spectrophotometer, Fig. 31. Based on this spectrum, the spectrometer had a bandwidth of 172 nm. spread over 256 photodiodes. This results in a 0.6 nm to diode ratio.

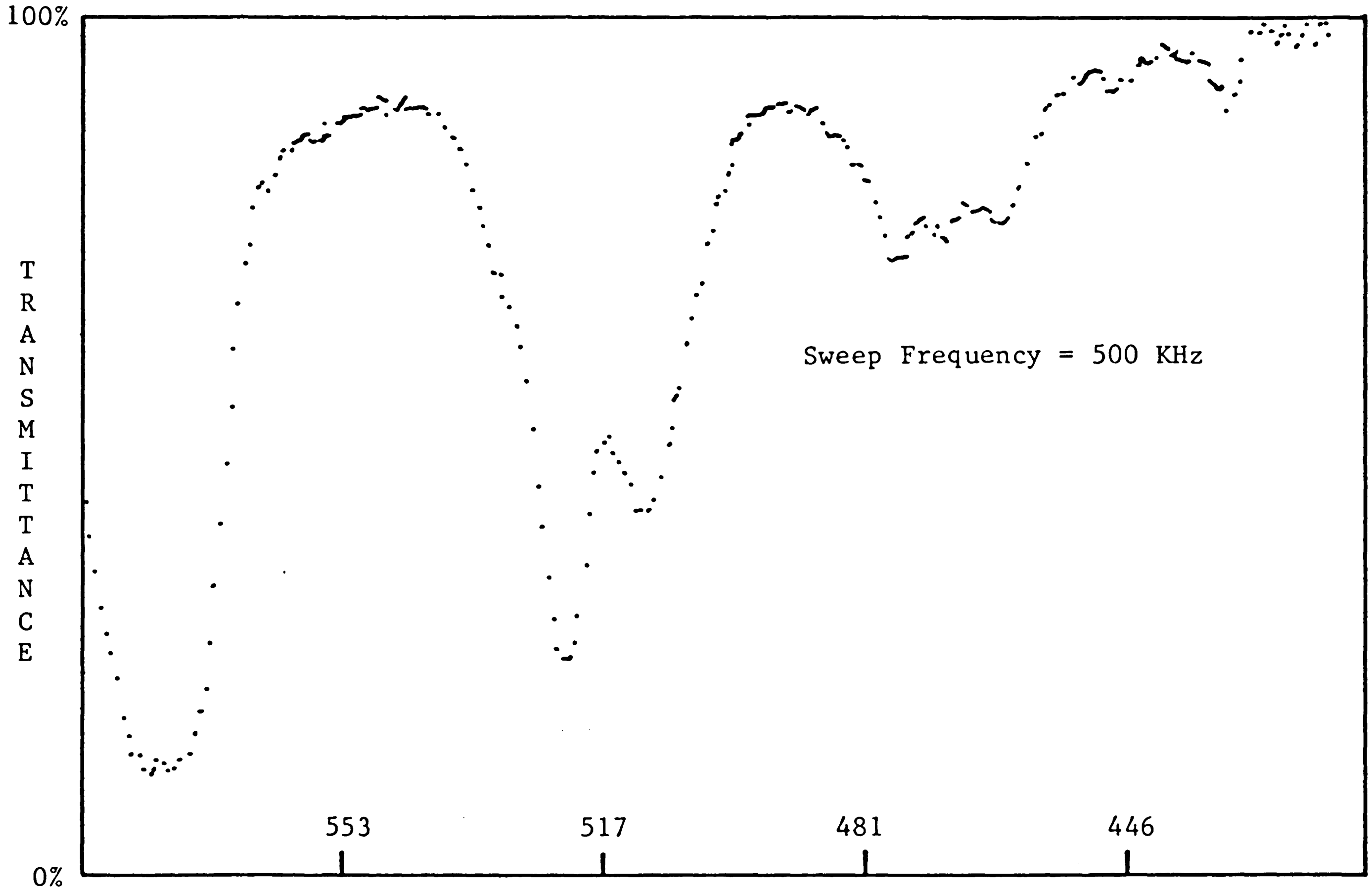


Figure 27. Plot of Transmittance versus Wavelength of neodymium magnesium nitrate corrected for detector responsivity

Wavelength (nm)

Spectral Conditions

Sweep Frequency - 50 KHz

Biomation Scale - 2 V full scale

Aqueous neodymium magnesium nitrate solution

Integration Times (msec)

1) 10

2) 8

3) 7

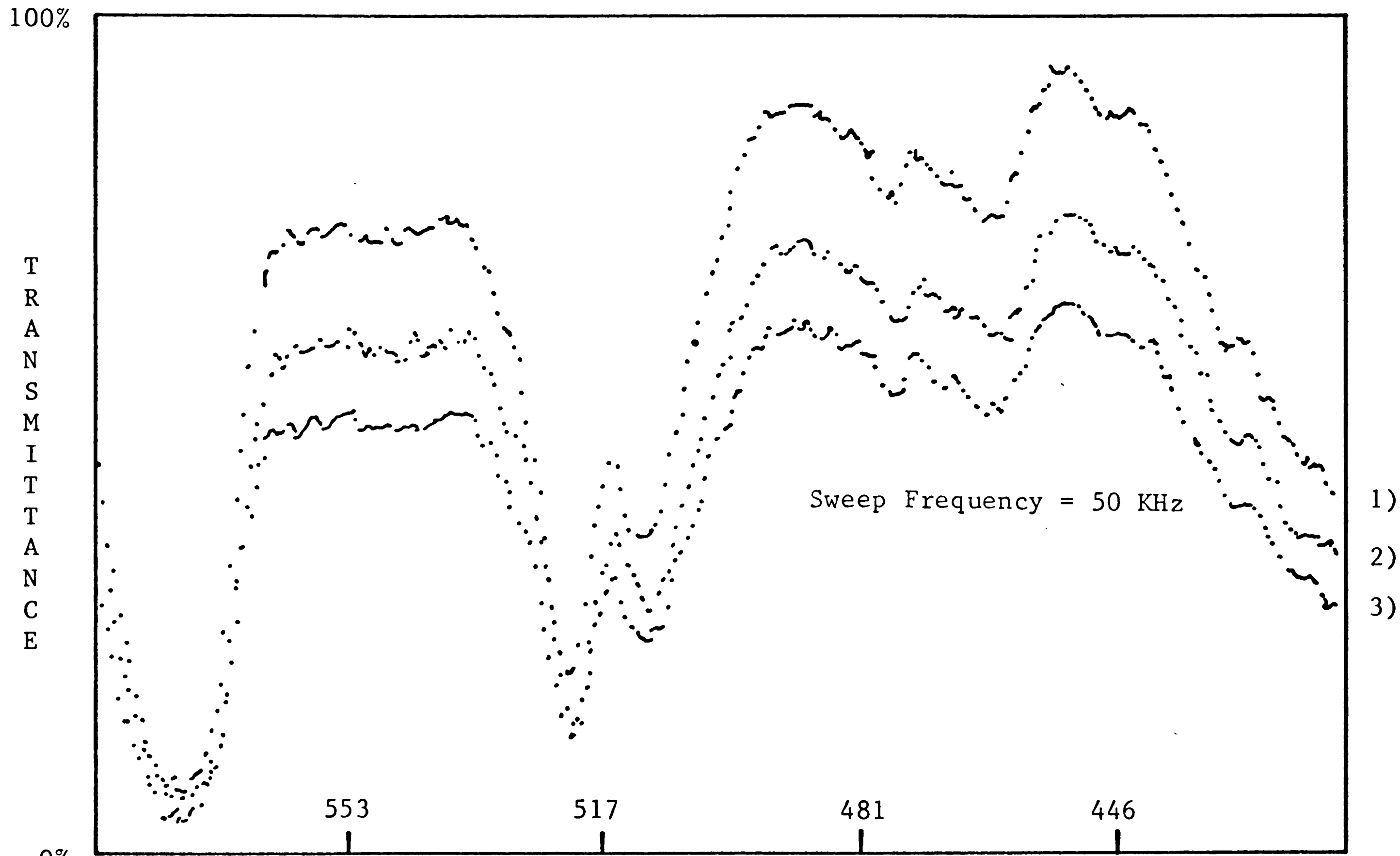


Figure 28 Plot of Transmittance versus Wavelength for neodymium magnesium nitrate at varying integration times

Wavelength (nm)

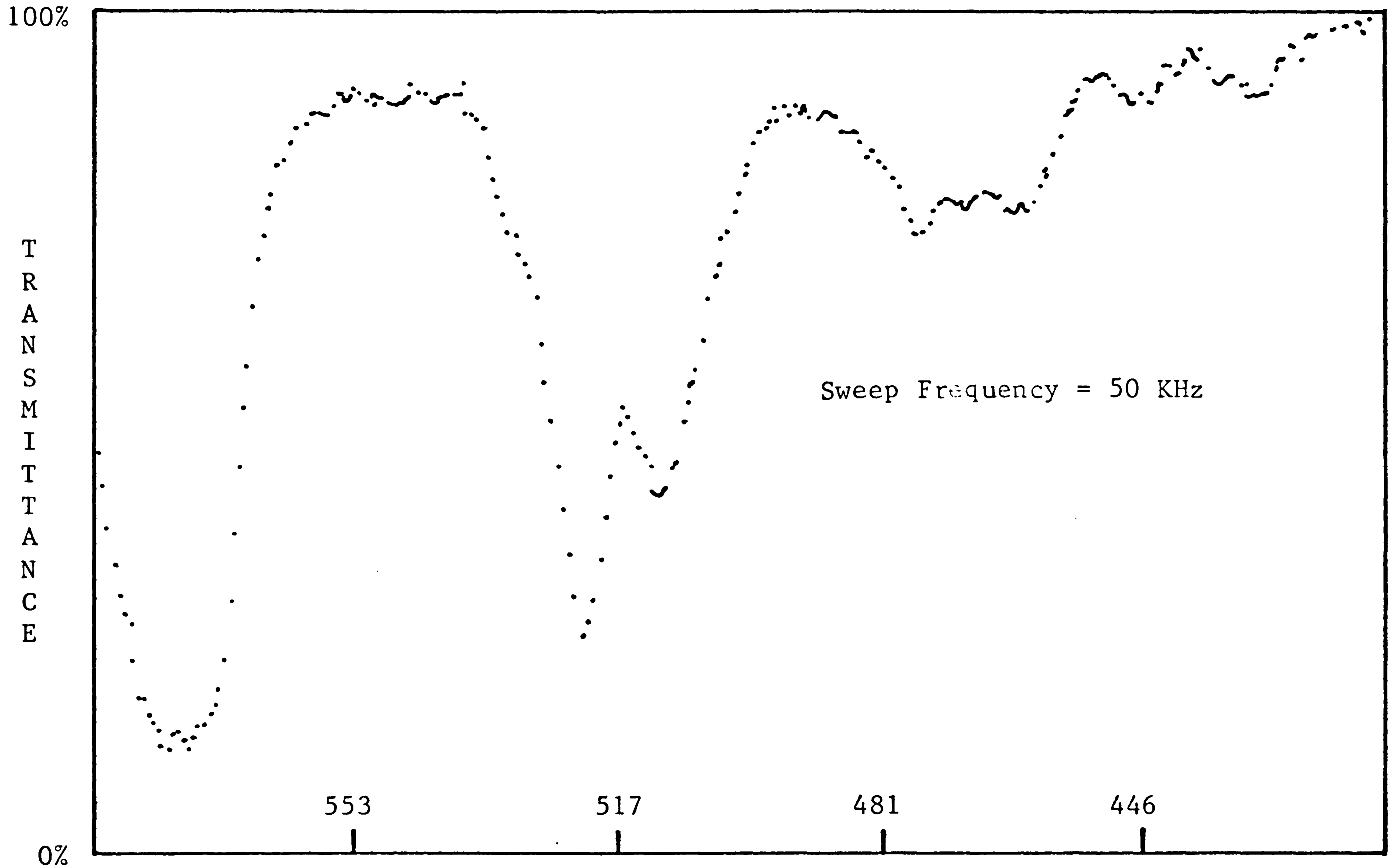


Figure 29 Plot of Transmittance versus Wavelength of neodymium magnesium nitrate corrected for detector responsivity

Wavelength (nm)

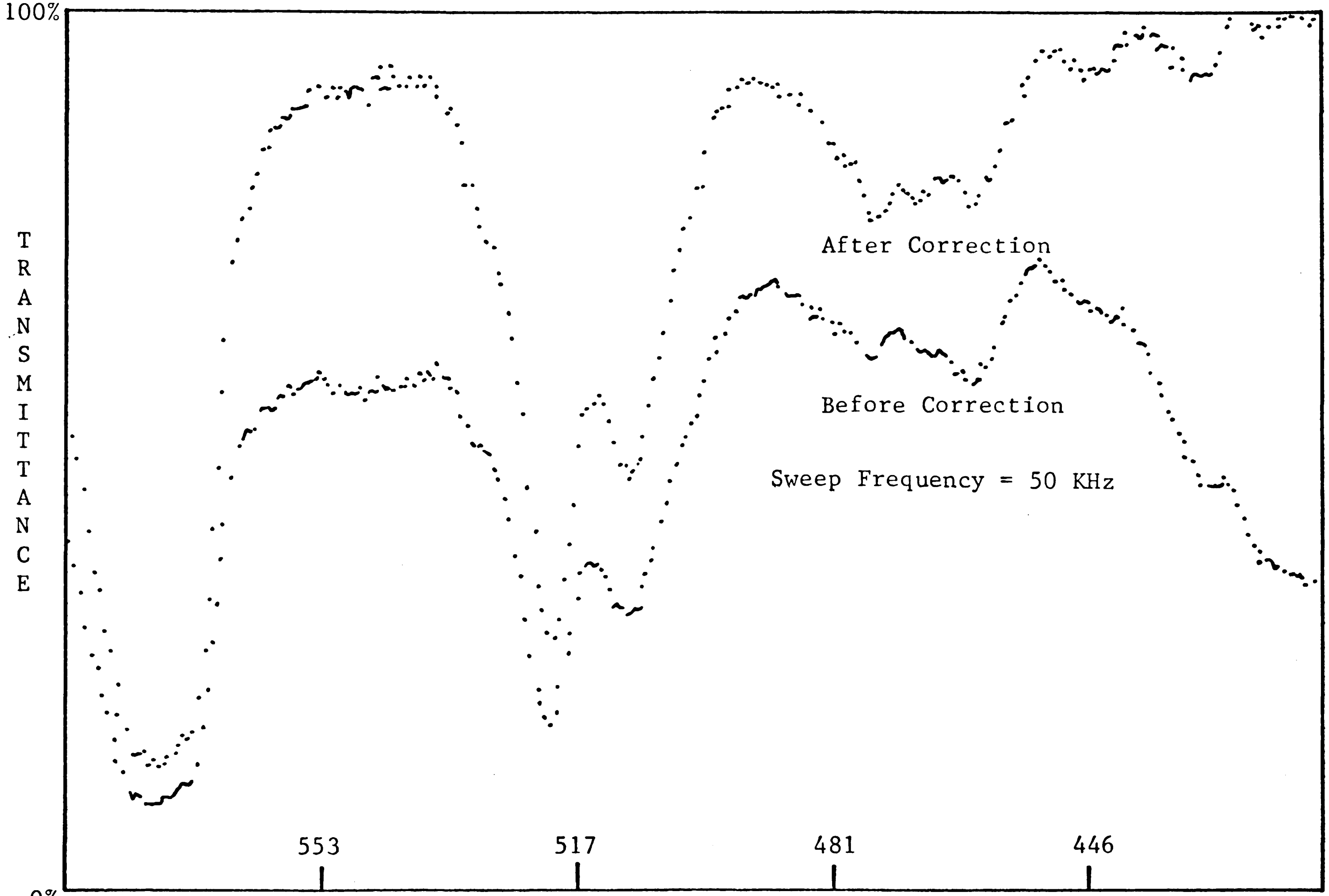


Figure 30 Plot of Transmittance versus Wavelength of neodymium magnesium nitrate before and after responsivity correction

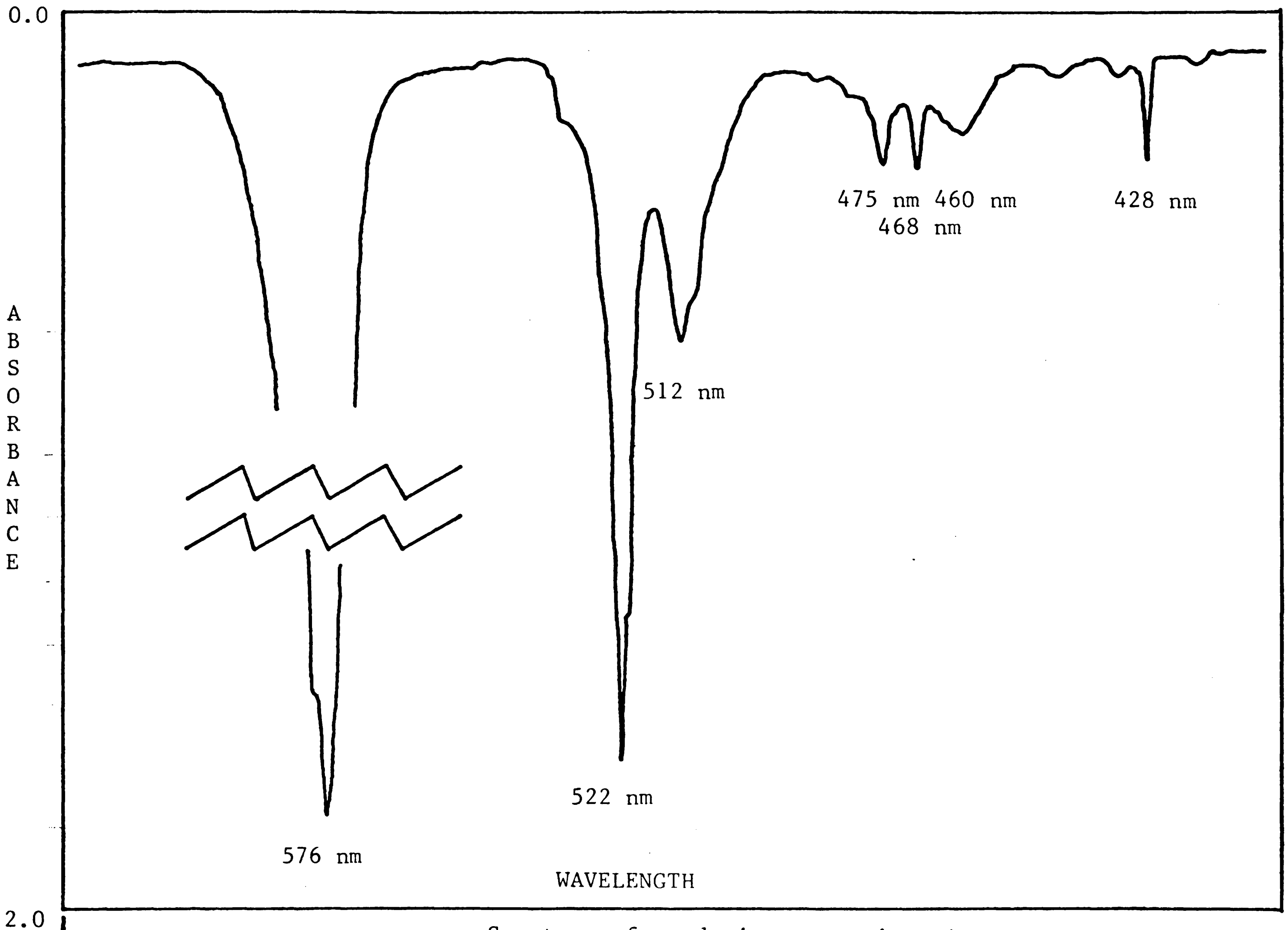


Figure 31 Spectrum of neodymium magnesium nitrate obtained from a Cary 14 spectrophotometer

CHEMICAL EXPERIMENTATION AND RESULTS

Equipment and Chemicals Used

A Spectra-Physics Model 3500B Gradient liquid chromatograph system was used for all HPLC separations. The chromatograph was equipped with a pressure monitor, dual pump controls, solvent programmer and a dual channel UV detector. A Hewlett Packard Model 680 6" strip chart recorder set for 10 mv full scale was used with this system. Only the absorbance of the column effluent at 254 nm was monitored. Unless otherwise noted, all HPLC separations were carried out on a Spherisorb S5W SS-3-250 column (3 mm x 25 cm), using filtered, technical grade hexanes containing 0.1% 2-propanol (IPA), as the solvent. Low pressure separations were performed using Fisher neutral or basic alumina, 80-200 mesh. Spectra used to compare the multiwavelength system to commercially available spectrophotometers were produced using a Cary 14 spectrophotometer scanning from 340 nm to 700 nm using matched 1 cm quartz cells.

Azobenzene, azoxybenzene, hydrazobenzene, α-D-glucose, Orange IV and 4,4'-methylenebis(N,N-dimethylaniline) were obtained from Eastman Organic Chemicals, Rochester, NY. Lithium tetrahydridoaluminate (LAH) was from Ventron Corp., Danvers, MA. The nitrobenzene, 2-propanol, aniline, sodium nitrate and zinc dust were of Fisher certified ACS grade. All of the acids and bases used in our work were of Fisher reagent grade, as was the Methyl Green. Rose Bengal was obtained from Matheson, Coleman & Bell. The solvents used for sample preparations, separations and visible spectra were of technical grade and filtered prior to use with a Millipore filter funnel using type LS filters (Millipore Filter Co., Bedford, MA).

Preparation and Chromatograms of Nitrobenzene Standards

In the reduction of nitrobenzene to azobenzene, there is the possibility that more than two compounds are present in the reaction mixture at one time. The compounds listed in Table 7 may be present in the reaction mixture as intermediates or final products.

TABLE 7

POSSIBLE COMPOUNDS PRESENT

1) Nitrobenzene
2) N-Phenylhydroxylamine
3) Nitrosobenzene
4) cis- and trans-Azoxybenzene
5) cis- and trans-Azobenzene
6) Hydrazobenzene

To interprete the chromatograms obtained during the nitrobenzene reduction, the retention times for the above compounds, except cis-azoxybenzene, were determined.

Identification of cis-and trans-Azobenzene

A column of neutral alumina, 80-200 mesh, Brockman Activity 1, 1¼" x 3½" was slurry packed with hexanes. A 0.25 g sample of azobenzene recrystallized from hexanes was dissolved in a minimum amount of hexanes (about 5 ml) and eluted on the column using hexanes. Fifty ml of the orange column effluent was collected and stored in the dark. A chromatogram of the sample was obtained immediately, (Fig.32a). A 3.7 ml aliquot of the sample was placed in a 1 cm quartz cell and illuminated at a distance of one inch for 3 3/4 hr with a short wavelength ultraviolet lamp. At the end of the illumination period, the sample was diluted back to its initial volume and a chromatogram was obtained (Fig. 32b).

Identification of Azoxybenzene and Nitrobenzene

A standard solution of 2.47×10^{-2} M nitrobenzene and a standard solution of 2.37×10^{-3} M azoxybenzene in hexanes (0.1% IPA) were used in conjunction with the previously obtained sample of column effluent. Chromatograms (Fig. 33) were obtained for all three samples.

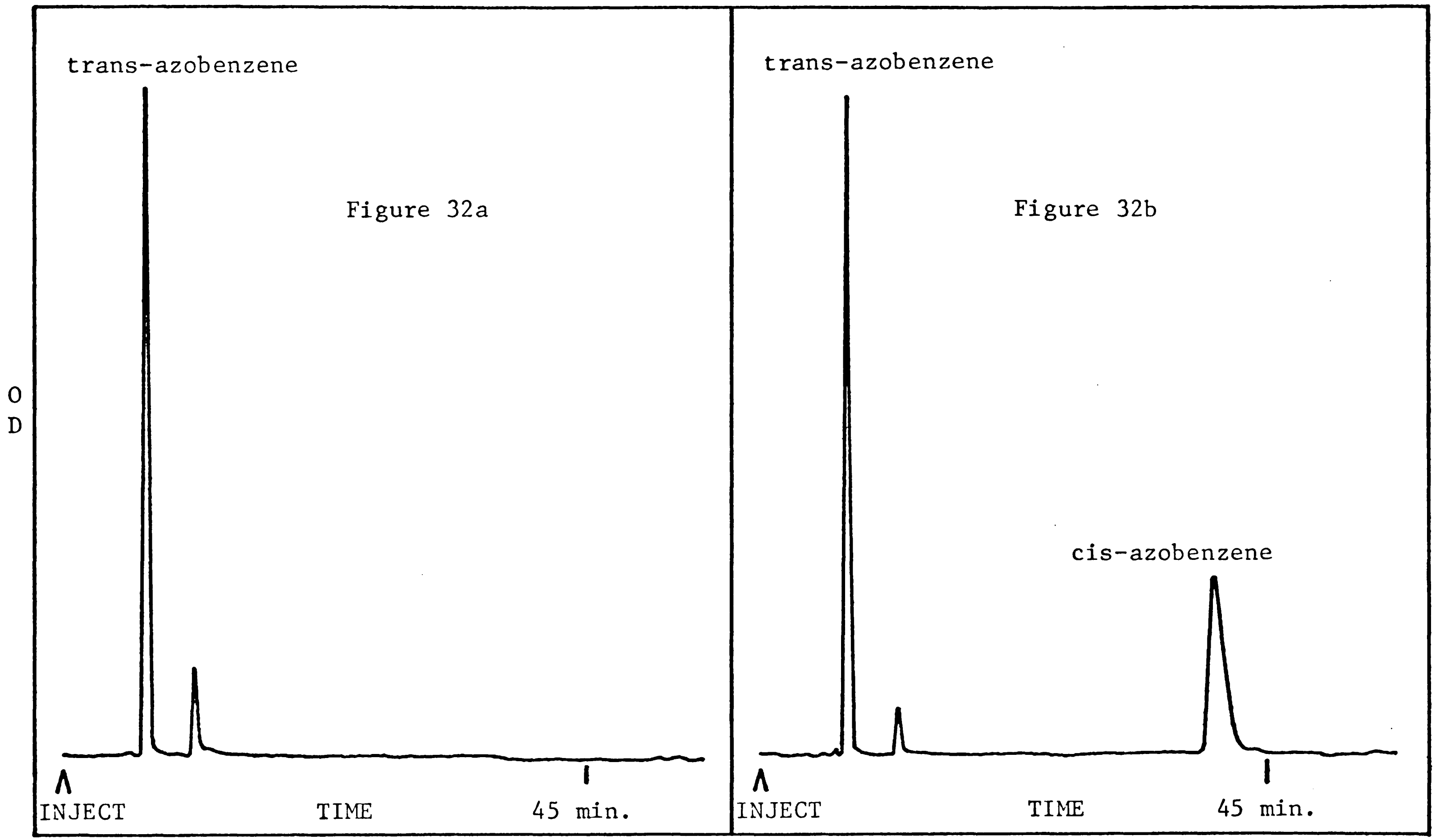
Identification of N-Phenylhydroxylamine

A sample of N-phenylhydroxylamine was prepared by reducing nitrobenzene with zinc dust in an aqueous ammonium chloride solution. The product was recrystallized with benzene-petroleum ether and dried in air, m.p. 80-80.5^{o} uncorrected. A saturated hexane solution of the product was prepared and a chromatogram obtained (Fig. 33). The solution contained less than 8.0 mg (7.3×10^{-5} moles) in 10 ml hexanes (0.1% IPA). The solution was no more than 7.3×10^{-3} M.

Figures 32a, 32b   Effect of irradiating a solution of trans-azobenzene with ultraviolet light

Separation Conditions

Column	- Spherisorb S5W, 250 mm x 3 mm
Pressure	- 100 psi
Flow Rate	- 0.8 ml/min
Temperature	- 26^{o}
Wavelength	- 254 nm
O.D.	- 1.28
Solvent System	- Hexanes with 0.1% IPA
Chart Speed	- 4 in/hr



Figures 32a, 32b Effect of irradiating a solution of trans-azobenzene with ultraviolet light

Figure 33 Chromatograms of Nitrobenzene Standards

Separation Conditions

Column	-	Spherisorb S5W, 250 mm x 3 mm
Pressure	-	150 psi
Flow Rate	-	0.48 ml/min
Temperature	-	23^{o}
Wavelength	-	254 nm
O.D.	-	1.28
Chart Speed	-	8 in/hr
Solvent System	-	Hexanes with 0.1% IPA

Compounds separated:

1) trans-azobenzene
2) nitrobenzene, 2.47×10^{-2} M
3) azobenzene, 2.37×10^{-3} M
4) nitrosobenzene, 5×10^{-3} M
5) N-phenylhydroxylamine, saturated (7.3×10^{-3} M)

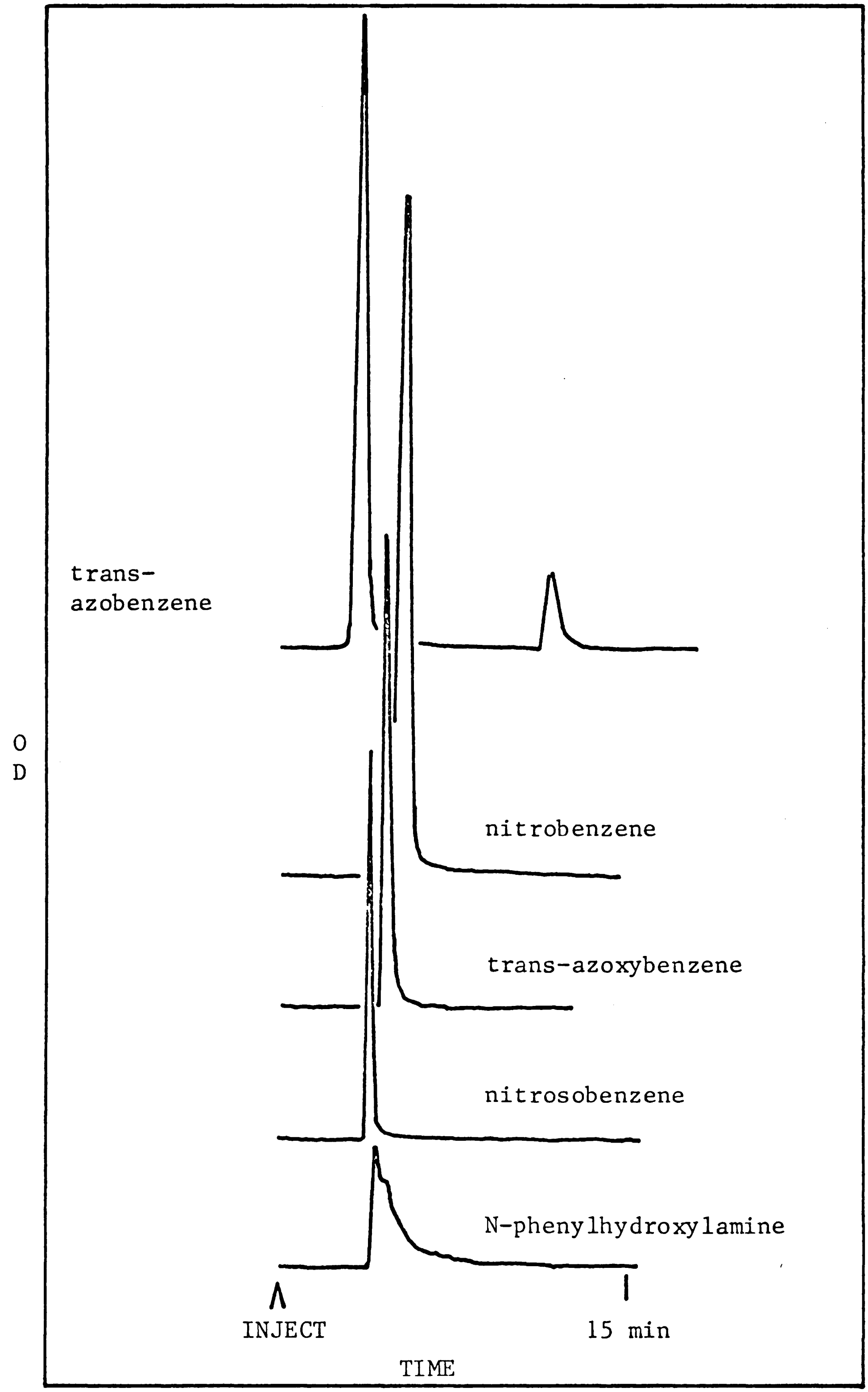


Figure 33 Chromatograms of Nitrobenzene Standards

Identification of Nitrosobenzene

A 5 x 10^{-3} M solution of nitrosobenzene (m.p. 64-67°, Aldrich Chemical Co., Milwaukee, WI) in hexanes (0.1% IPA) was prepared and a chromatogram obtained (Fig. 33).

Identification of Hydrazobenzene

A solution of hydrazobenzene (Eastman P321) was prepared with hexanes (0.1% IPA) and a chromatogram obtained (Fig. 34a). A solution of 0.15 g copper chloride dihydrate ($CuCl_2 \cdot 2H_2O$; 8.7 x 10^{-4} mol) in 5 ml water and 2 ml of a 1N sodium hydroxide aqueous solution was added to the hydrazobenzene solution. Oxygen (Airco, 99.9%) was then bubbled through the solution for 15 minutes and then an additional 33 min. After each time period, the organic layer was decanted and the aqueous layer was washed with 5 ml of hexanes. The combined organic layers were dried with either anhydrous calcium chloride or anhydrous magnesium sulfate, filtered and a chromatogram obtained (Fig. 34b and Fig. 34c).

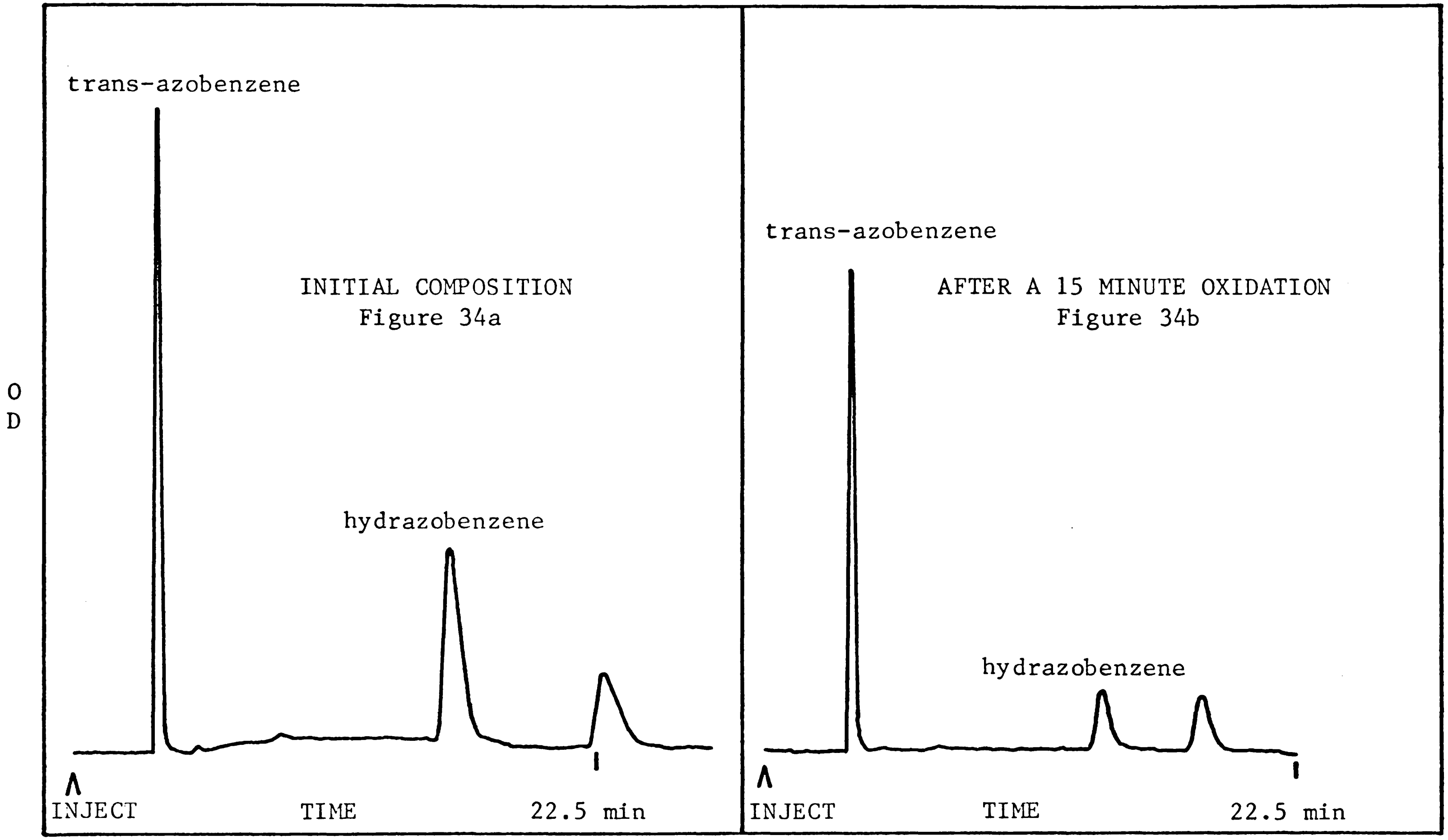
Reduction of Nitrobenzene and Results

Zinc dust, 26.6 g (0.4 mol) was suspended with stirring in a solution of 75 ml water and 5 ml concentrated (37%) hydrochloric acid in a 500 ml round bottomed flask equipped with stirrer, condenser and a rubber septum. After five minutes, 32.5 g (0.8 mol) sodium hydroxide and 250 ml methanol were added and the suspension was cooled to room temperature. To this, 21 ml (0.2 mol) of nitrobenzene was added with stirring and refluxing begun.

Figures 34a, 34b — Effect of oxygen on the composition of a hydrazobenzene/hexanes solution

Separation Conditions

Column	-	Spherisorb S5W, 250 mm x 3 mm
Pressure	-	230 psi
Flow Rate	-	0.12 ml/min
Temperature	-	26^{o}
Wavelength(s)	-	254 nm
O.D.	-	1.28
Chart Speed	-	8 in/hr
Solvent System	-	Hexanes with 0.1% IPA



Figures 34a, 34b   Effect of oxygen on the composition of a hydrazobenzene/hexanes solution

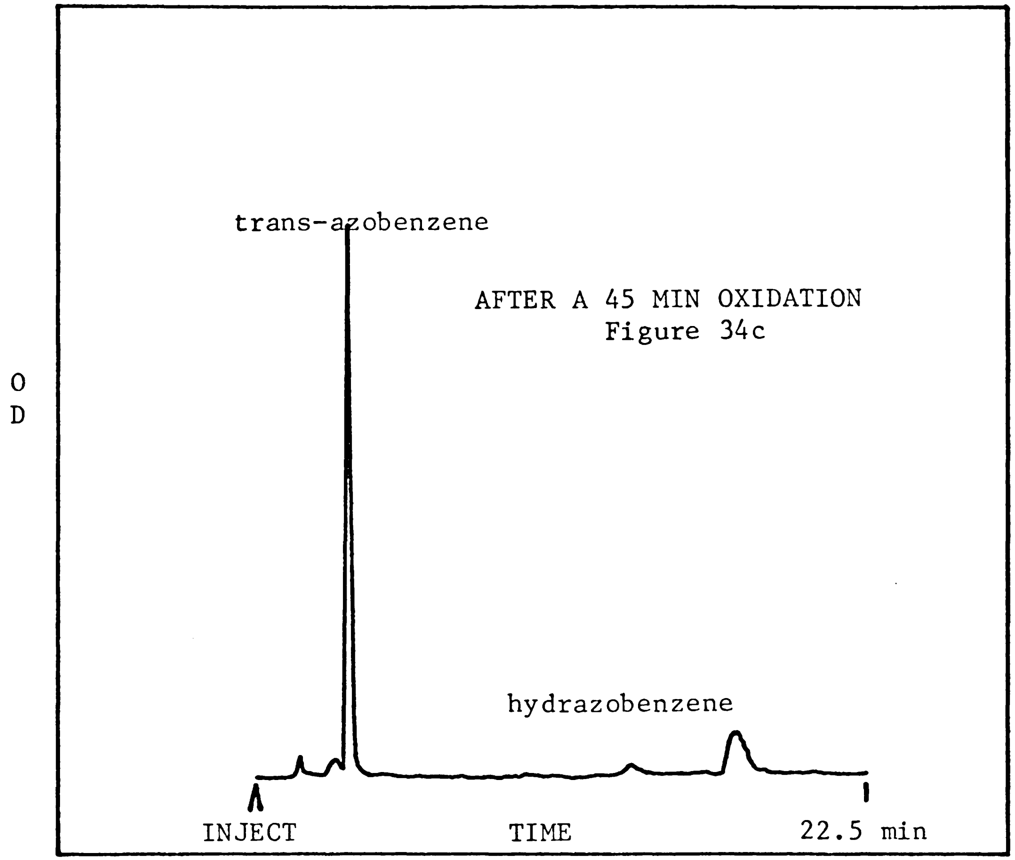


Figure 34c Effect of oxygen on the composition of a hydrazobenzene/hexanes solution (cont.)

At appropriate intervals, 6 ml samples of the reaction mixture were taken and centrifuged. The supernatant was decanted and the solid residue washed three times with 4 ml portions of methanol. The combined decanted solutions were evaporated to dryness or to a thick slurry, washed and diluted to 10 ml with hexanes containing 0.1% 2-propanol (v/v). Chromatograms of these solutions were obtained using both the 254 nm UV detector and the multiwavelength detector system, Fig. 35a-i and Fig. 36a-i.

Table 8 shows the peak height, width at half height and area for the first component eluted in Fig. 35a-i.

TABLE 8

CALCULATED AREA FOR THE FIRST COMPONENT ELUTED IN FIG. 35a-i

Time	Height	Width (at half height)	Area
0.0	0	0	0
1.5	8.5	1	8.5
2.5	18	0.9	16.2
3.0	24	1	24
3.5	30	1	30
4.0	58	1	58
4.5	65	1.5	97.5
6.0	68	1.7	115.6
8.0	67.5	2	135

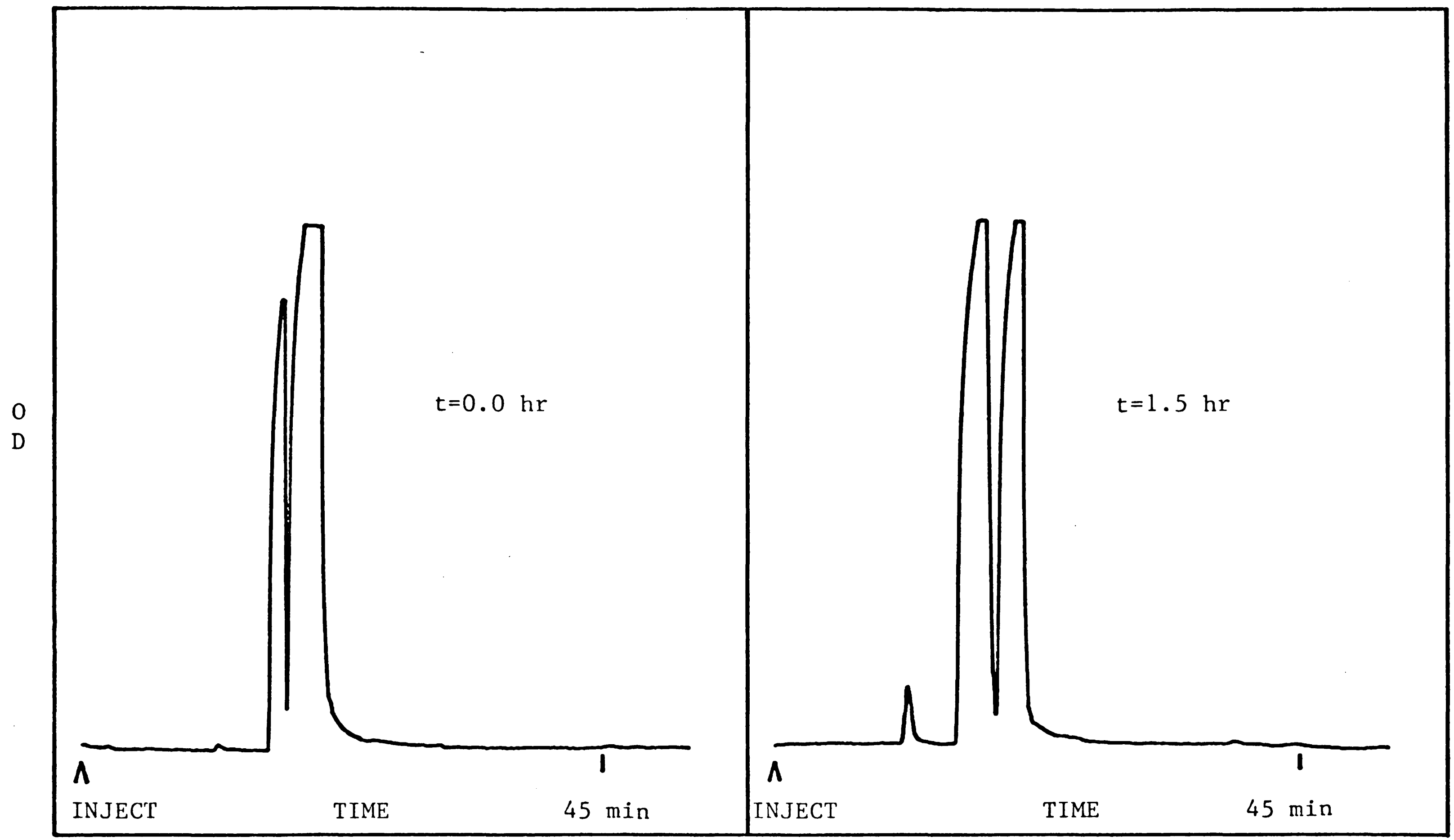
A plot of the peak versus time can be seen in Fig. 37. The shape of the plot is very similar to what would be expected if the concentration of the second product in a simple three step reaction, A→B→C, had been monitored with time. Based on the retention times of the standard solutions, the first peak in Fig. 35a-i was mostly likely due to

Figures 35a - 36i   Chromatograms obtained during the reduction of Nitrobenzene

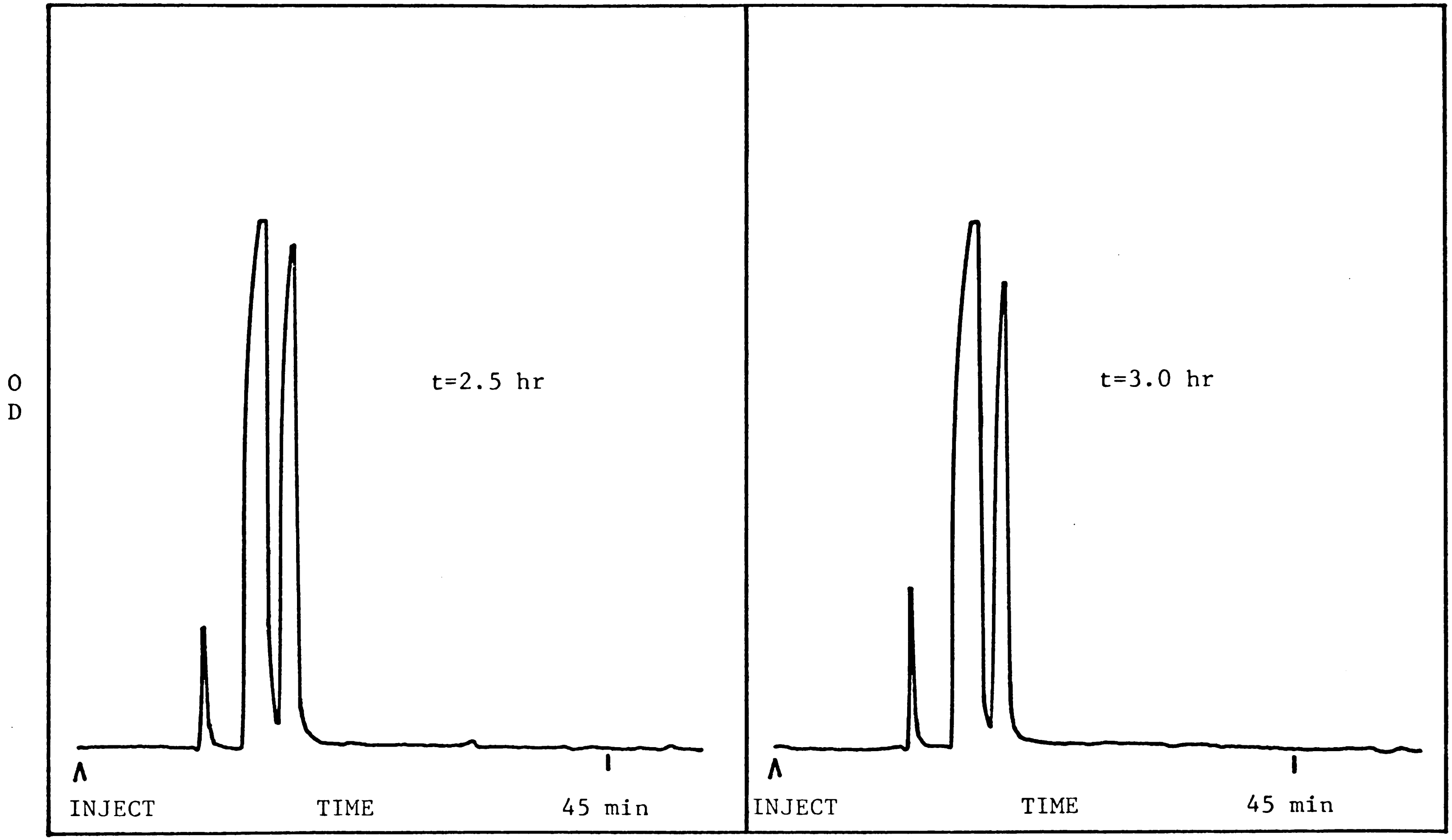
Separation Conditions

Column	-	Spherisorb S5W, 250 mm x 3 mm
Pressure	-	80 psi
Flow Rate	-	0.36 ml/min
Temperature	-	24^o
Wavelength(s)	-	254 nm
O.D.	-	2.56
Chart Speed	-	4 in/hr
TBS	-	10 sec
ITEG	-	2 msec
Array Number(s)	-	192
Sweep Frequency	-	500 KHz
Biomation Scale	-	2 V full scale
Solvent System	-	Hexanes with 0.1% IPA

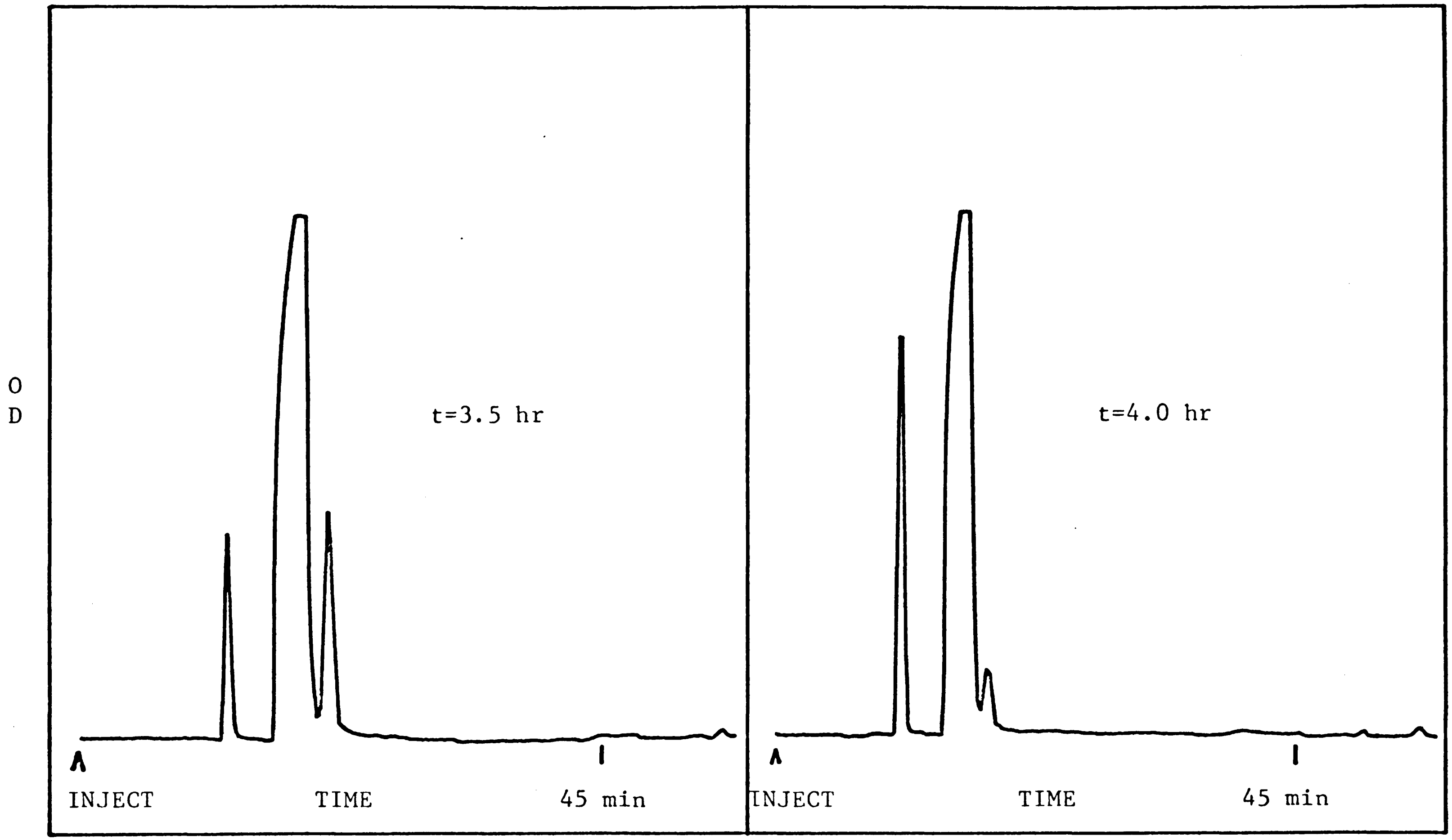
Compounds separated: Nitrobenzene reduction



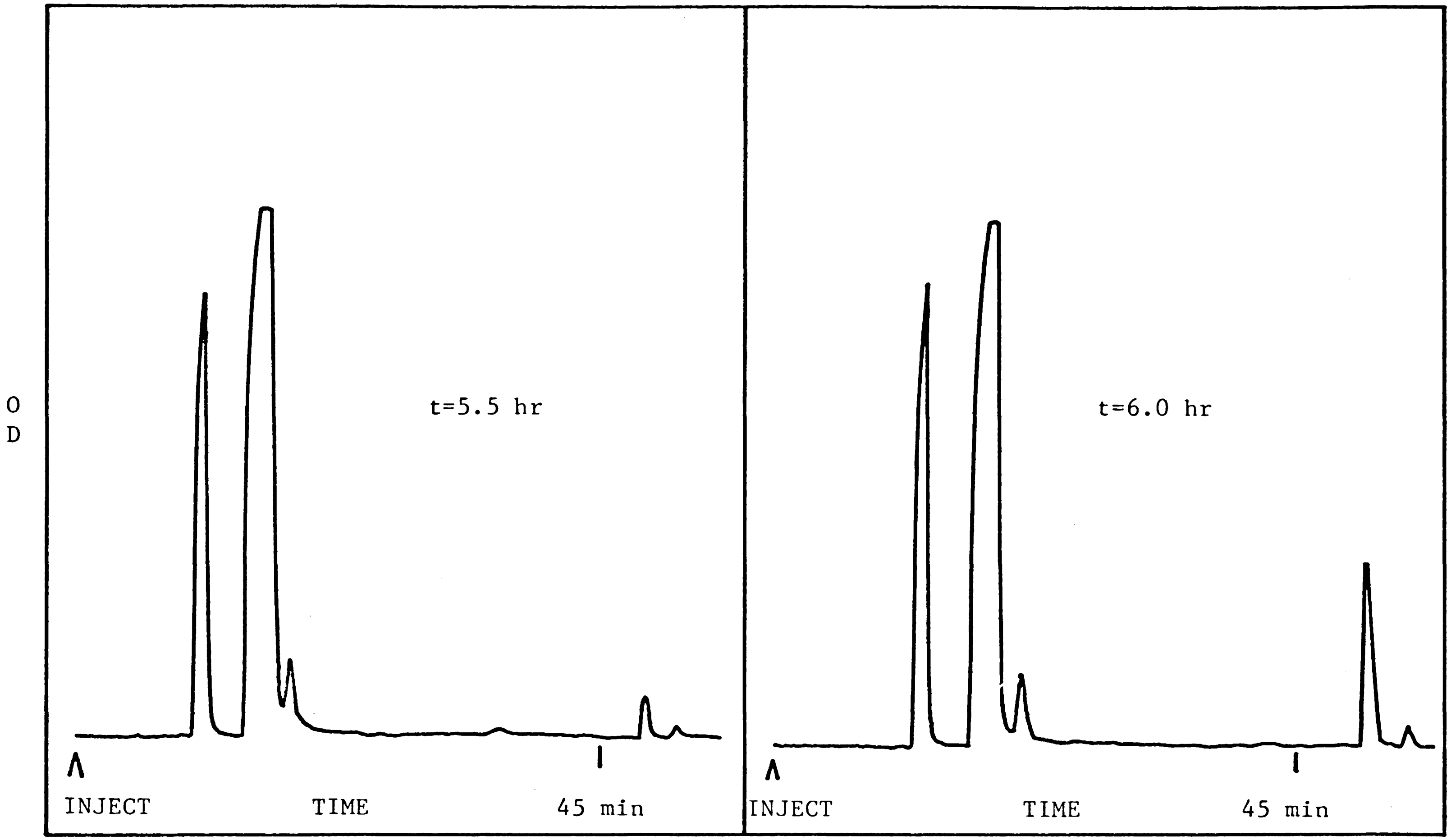
Figures 35a, 35b Chromatograms obtained during the reduction of Nitrobenzene



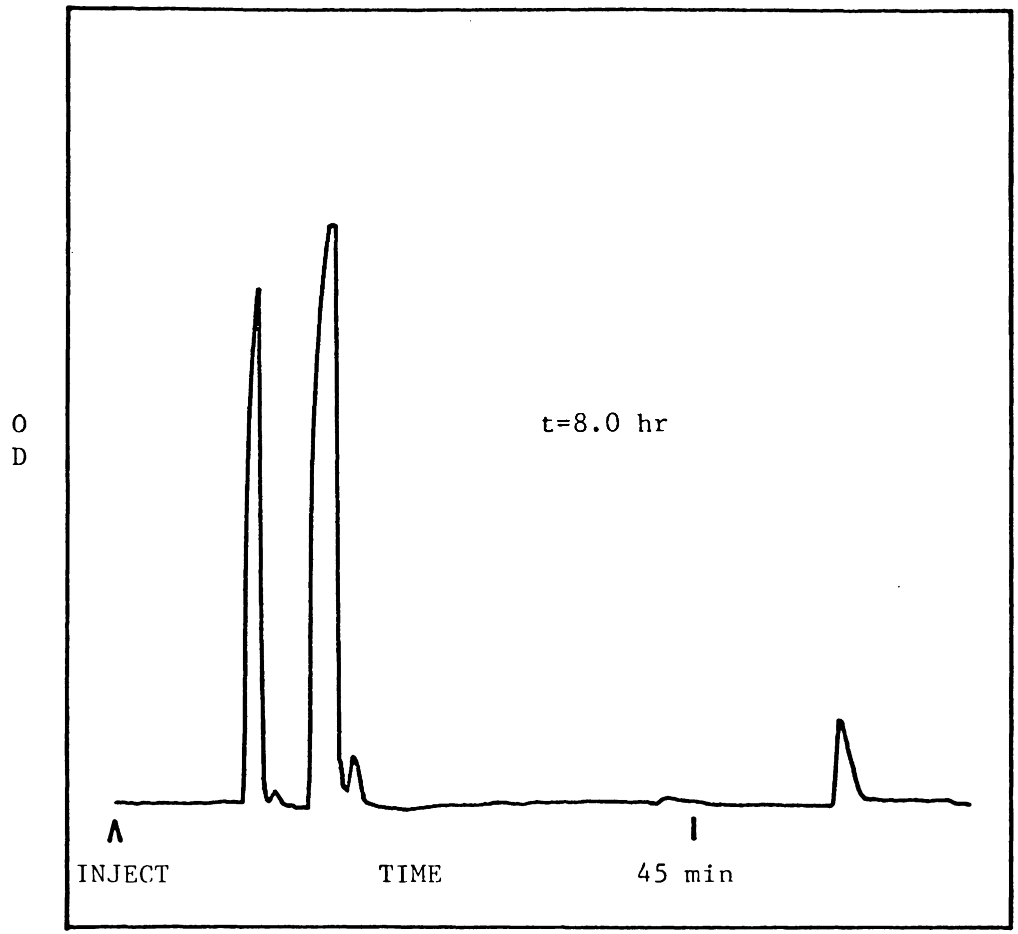
Figures 35c, 35d Chromatograms obtained during the reduction of Nitrobenzene (cont.)



Figures 35e, 35f Chromatograms obtained during the reduction of Nitrobenzene (cont.)

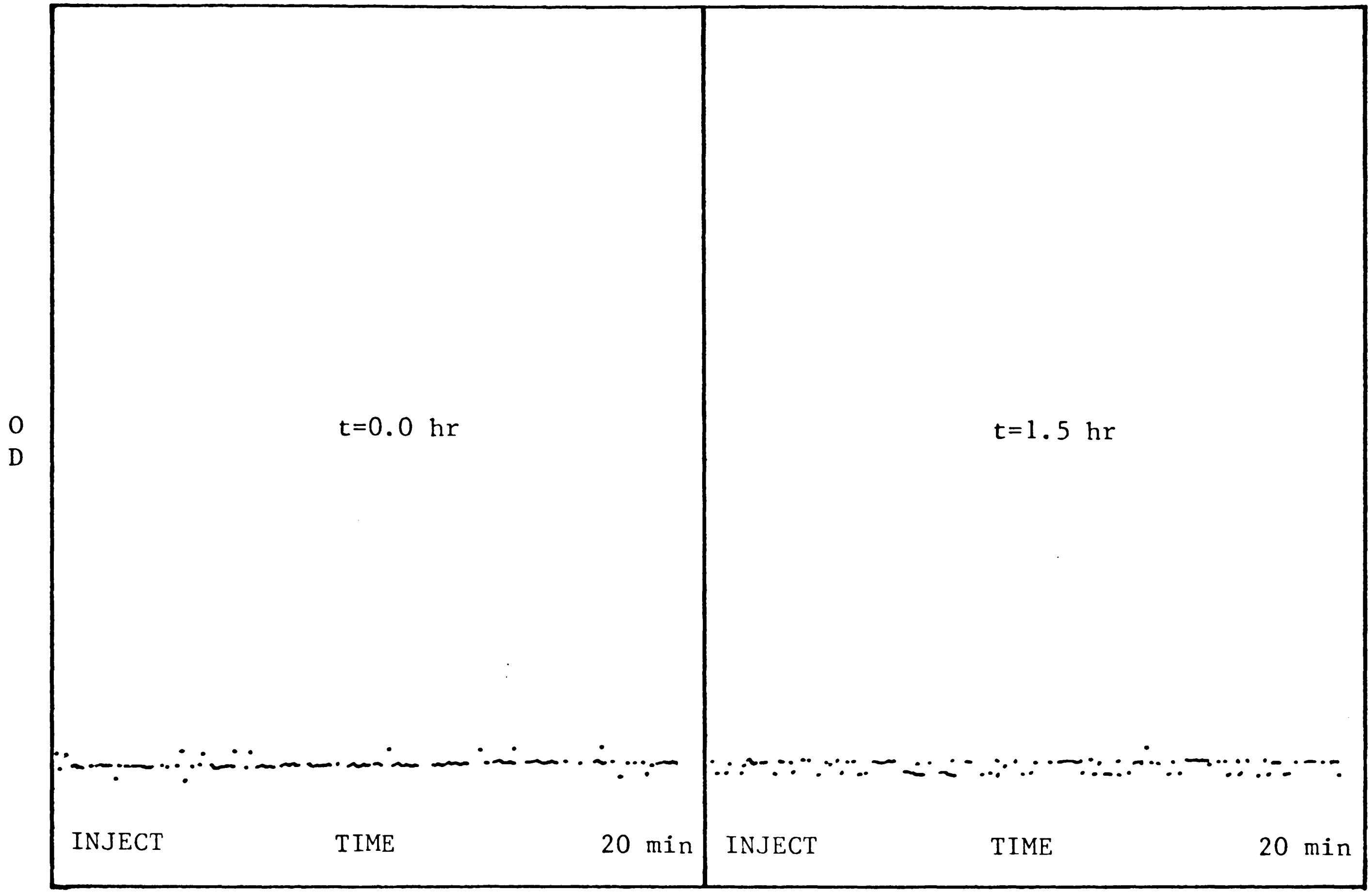


Figures 35g, 35h Chromatograms obtained during the reduction of Nitrobenzene (cont.)

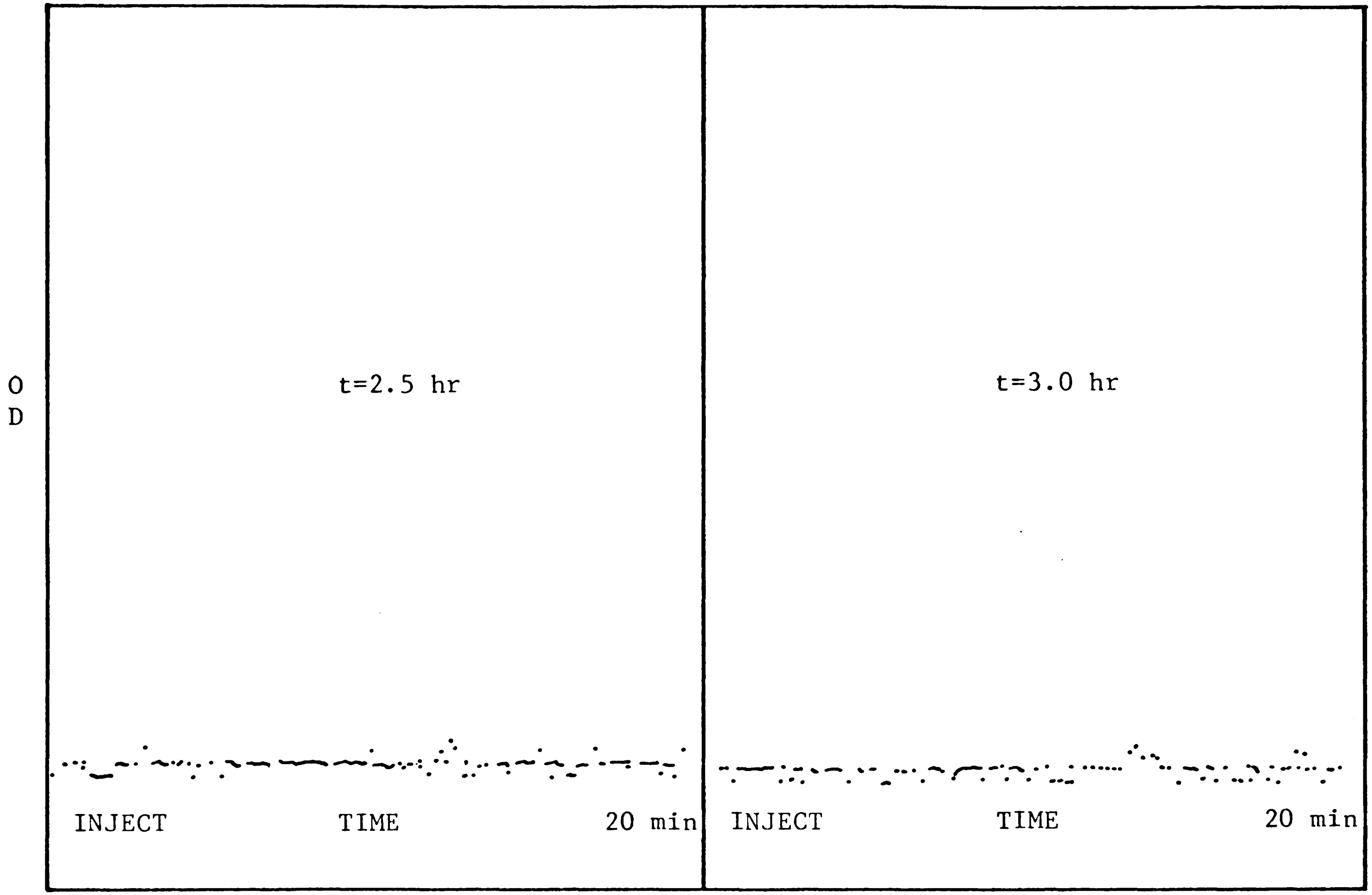


Chromatogram obtained during the reduction of Nitrobenzene
(cont.)

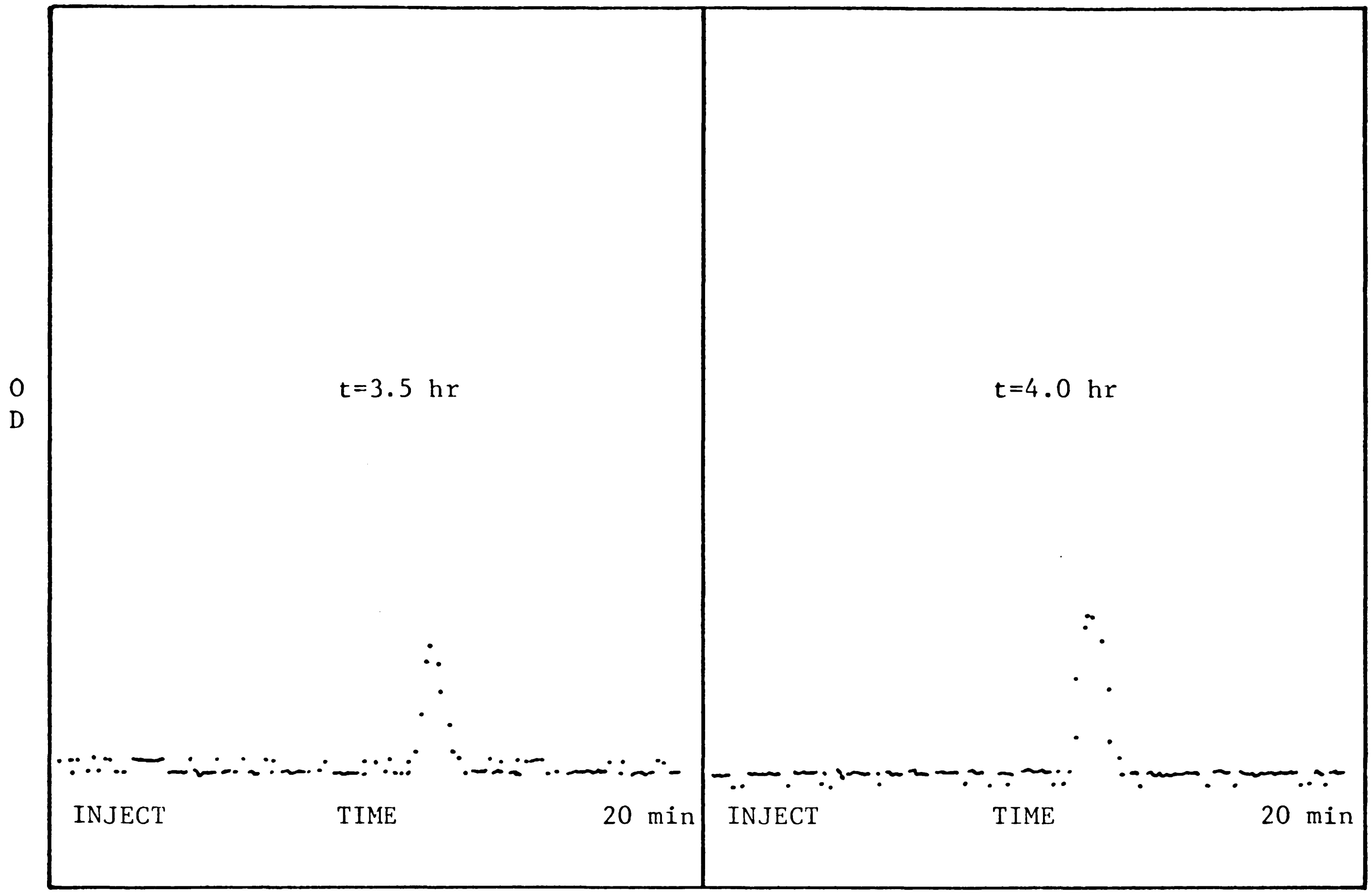
Figure 35i



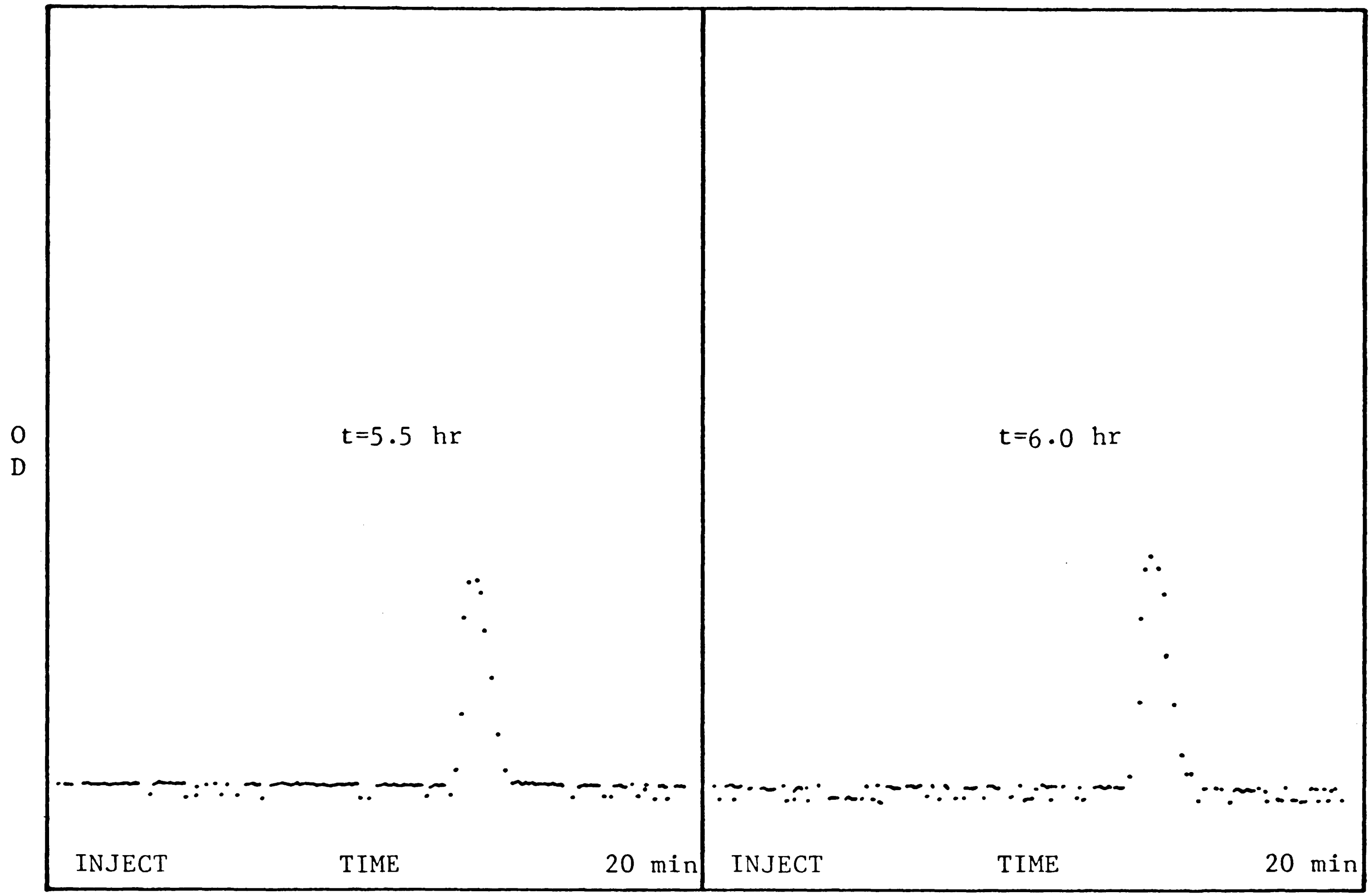
Figures 36a, 36b Chromatograms obtained from the reduction of Nitrobenzene using the multiwavelength detector (AN=192)



Figures 36c, 36d Chromatograms obtained from the Nitrobenzene reduction using the multiwavelength detector (AN=192)



Figures 36e, 36f   Chromatograms obtained from the reduction of Nitrobenzene using the multiwavelength detector (AN=192)



Figures 36g, 36h Chromatograms obtained from the reduction of Nitrobenzene using the multiwavelength detector (AN=192)

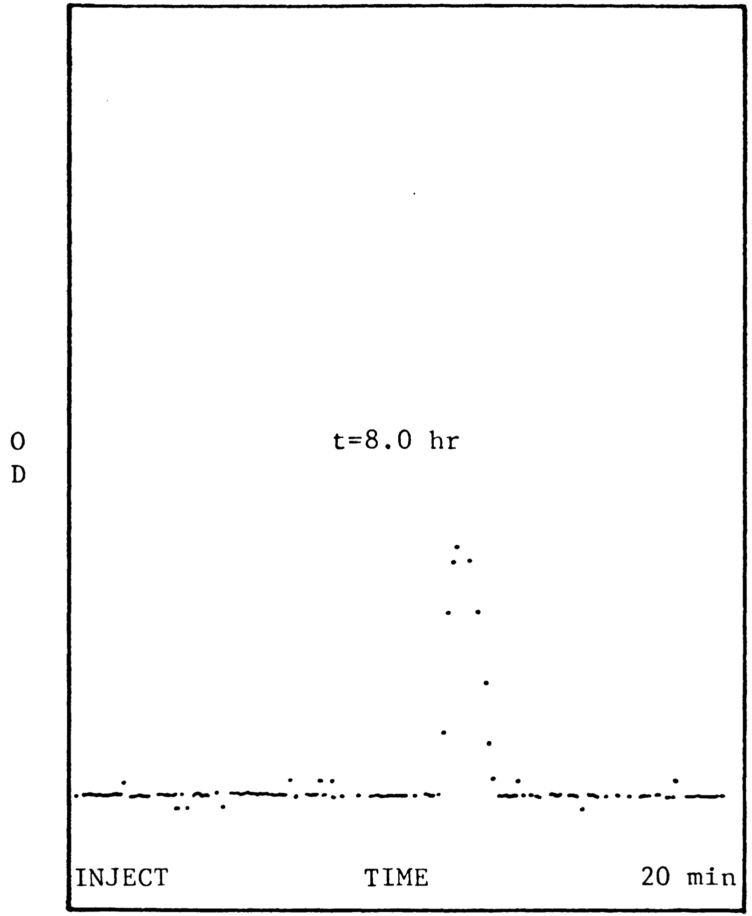


Figure 36i Chromatogram obtained from the reduction of Nitrobenzene using the multiwavelength detector (AN=192)

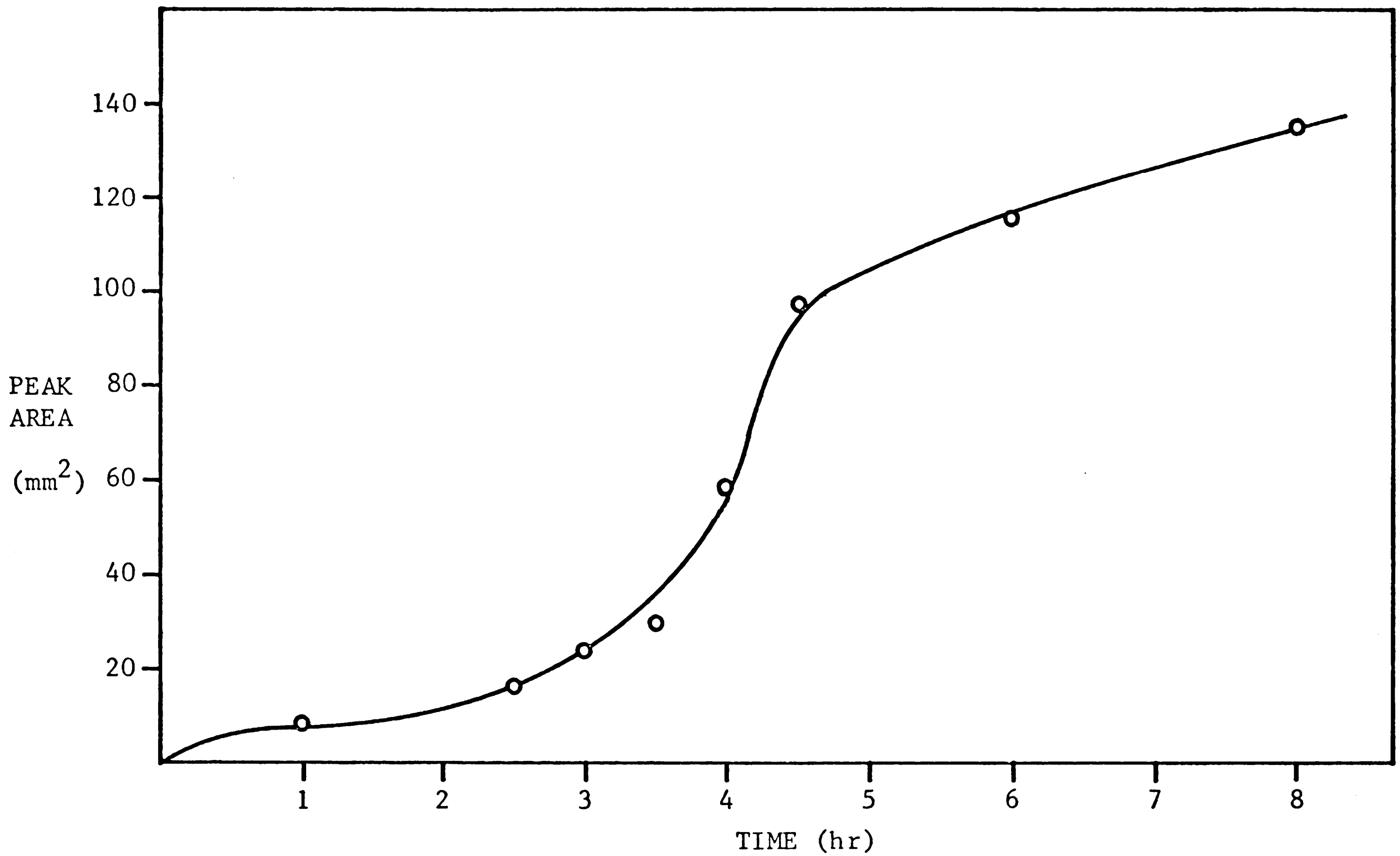


Figure 37 Plot of Azobenzene Peak Area versus Time

azobenzene. It also would appear that the third peak in Fig. 35a-i was due to nitrobenzene. The second peak in Fig. 35a-i might have been due to the presence of N-phenylhydroxylamine, nitrosobenzene or azoxybenzene. Note that at t=0, Fig. 35a, very little azobenzene was present and that the area of the third peak (nitrobenzene) decreased with time.

The appearance of azobenzene can also be observed in the plots produced by the multiwavelength detector. In the reaction mixture, only azobenzene had an appreciable visible spectrum. Therefore, the multiwavelength detector detected only the colored component of the reaction mixture, azobenzene.

It has been well established that the reduction of nitrobenzene to azoxybenzene proceeds through the intermediates, N-phenylhydroxylamine and nitrosobenzene. The mechanism of this reaction has been studied, and appears to be very complex. A simplified version of this mechanism is as follows:

$$PhNO_2 + Zn \longrightarrow PhNO + Zn^{+2}$$

$$PhNO_2 + Zn + 2CH_3OH \longrightarrow PhNHOH + Zn^{+2} + 2HCHO$$

$$PhNHOH + PhNO_2 \longrightarrow 2PhNO + H_2O$$

$$PhNHOH + PhNO \longrightarrow PhNO{=}NPh + H_2O$$

$$PhNO{=}NPh + Zn \longrightarrow PhN{=}NPh + Zn^{+2}$$

$$Ph = C_6H_5$$

The purpose of studying this mechanism was to try to determine the identity of the substance responsible for the second peak in the chromatograms of the nitrobenzene reduction (Figs. 35a-i). Due to the insolubility of N-phenylhydroxylamine, determined in the preparation of the standard solutions, it is unlikely that the middle peak is due to this compound. Ogata (40) and Russell (41) have both reported that the rate of condensation of N-phenylhydroxylamine and nitrosobenzene to produce azoxybenzene is much faster than the initial reduction of nitrobenzene. At the same time, neither N-phenylhydroxylamine or nitrosobenzene was thought to be present as determined by spectrophotometry in the range of 240 nm to 300 nm. If this was true, then the middle peak shown in Figs. 35a-i was probably due to azoxybenzene. If so, the overall reduction of nitrobenzene to azobenzene may be viewed as a three step reaction as follows:

$$PhNO_2 \longrightarrow PhN(O){=}NPh \longrightarrow PhN{=}NPh$$

Based on the chromatograms shown in Fig. 35, it would appear that the reduction of azoxybenzene to azobenzene is the rate determining step for the nitrobenzene reduction.

The reaction is known to be sensitive to the surface area, porosity and purity of the zinc dust used. If it is assumed that under the reaction conditions used, the reduction of azoxybenzene to azobenzene is not reversible, the failure to reduce more of the azoxybenzene is probably due to the nature of the zinc dust. Unfortunately, an excess of zinc dust can not be used because of the possibility of further reducing the azobenzene to colorless hydrazobenzene. However, the initial reduction of nitrobenzene to N-phenylhydroxylamine and/or nitrosobenzene is mild enough, that at the end of the eight hours, most of the nitrobenzene has been reduced to azoxybenzene.

Preparation of Diazepines

Preparation of 2,2' Dinitro-4,4'-methylene-bis(N,N-dimethylaniline)

A solution of 5.06 g (0.02 mol) 4,4'-methylenebis(N,N-dimethylaniline) in 50 ml conc. (97%) sulfuric acid was cooled with stirring to -9^{o} with an ice-salt bath. A solution of 17 ml conc. (98%) sulfuric acid and 13 ml conc. (70%) nitric acid was added with stirring to the cooled solution over a 15 min period. After all of the nitrating solution was added and the nitration completed, the solution was stirred into a slurry of ice and 275 ml 30% ammonium hydroxide (excess). The resulting orange precipitate was filtered by suction and washed with water until the filtrate was neutral to litmus. When dried in air, 6.35 g, 93% yield, of product was obtained, m.p. 189^{o} - 191.5^{o}, reported 191.5^{o} (44).

Preparation of 3,8-Bis(N,N-dimethylamino)-11H-dibenzo(c,f)(1,2) diazepine Using Lithium Tetrahydridoaluminate

To a stirred refluxing slurry of 2.03 g (0.05 mol) lithium tetrahydridoaluminate, a slurry of 2.01 g (0.006 mol) 2,2'-dinitro-4,4'-methylenebis(N,N-dimethylaniline) in 150 ml tetrahydrofuran (THF) was added over a period of 1¼ hr. The resulting slurry was then refluxed for an additional 28 hr. The slurry was cooled to room temperature, an excess of water was added and the solution was filtered by suction. The filter cake was washed with 25 ml hot THF and the combined filtrates dried over excess anhydrous magnesium sulfate. After filtering, the solution was evaporated to dryness and dissolved in a minimum of methylene chloride. The solution was chromatographed over a 1" x 6" neutral alumina (80-200 mesh) column using methylene chloride as the elutant. The first band was collected and evaporated to dryness. The orange solid was recrystallized with 95% ethanol yielding 0.37g (22% yield) product, m.p. 210.5° - 212°, reported 213° (46).

<u>Preparation of 3,8-Bis(N,N-dimethylamino)-11H-dibenzo(c,f)(1,2) diazepine Using Alkaline Glucose</u>

A solution of 1.06 g (0.003 mol) 2,2'-dinitro-4,4'methylene-bis(N,N-dimethylaniline), 92.5 ml 95% ethanol, 35.5 ml 40% aqueous sodium hydroxide and 5.68 g (0.03 mol) α-D-glucose was heated for 1½hr at 65°. The resulting red-brown solution was let stand overnight at room temperature. The resulting orange precipitate was filtered by suction, washed with 25 ml boiling water and dried in air. The product, 0.53 g, 62% yield, was recrystallized with 95% ethanol and dried in air, m.p. 206° - 209°, reported 213° (46).

Solutions of 1.00×10^{-4} M 2,2'-dinitro-4,4'-methylenebis-(N,N-dimethylaniline) and 9.84×10^{-5} M 3,8-bis(N,N-dimethylamino)-11H-dibenzo(c,f)(1,2)diazepine in acetone were prepared. Visible spectra where obtained with a Cary 14 spectrophotometer using 1 cm matched quartz cells (Fig. 38) Because of the similarity in the spectra, no further work was done with this chemical system.

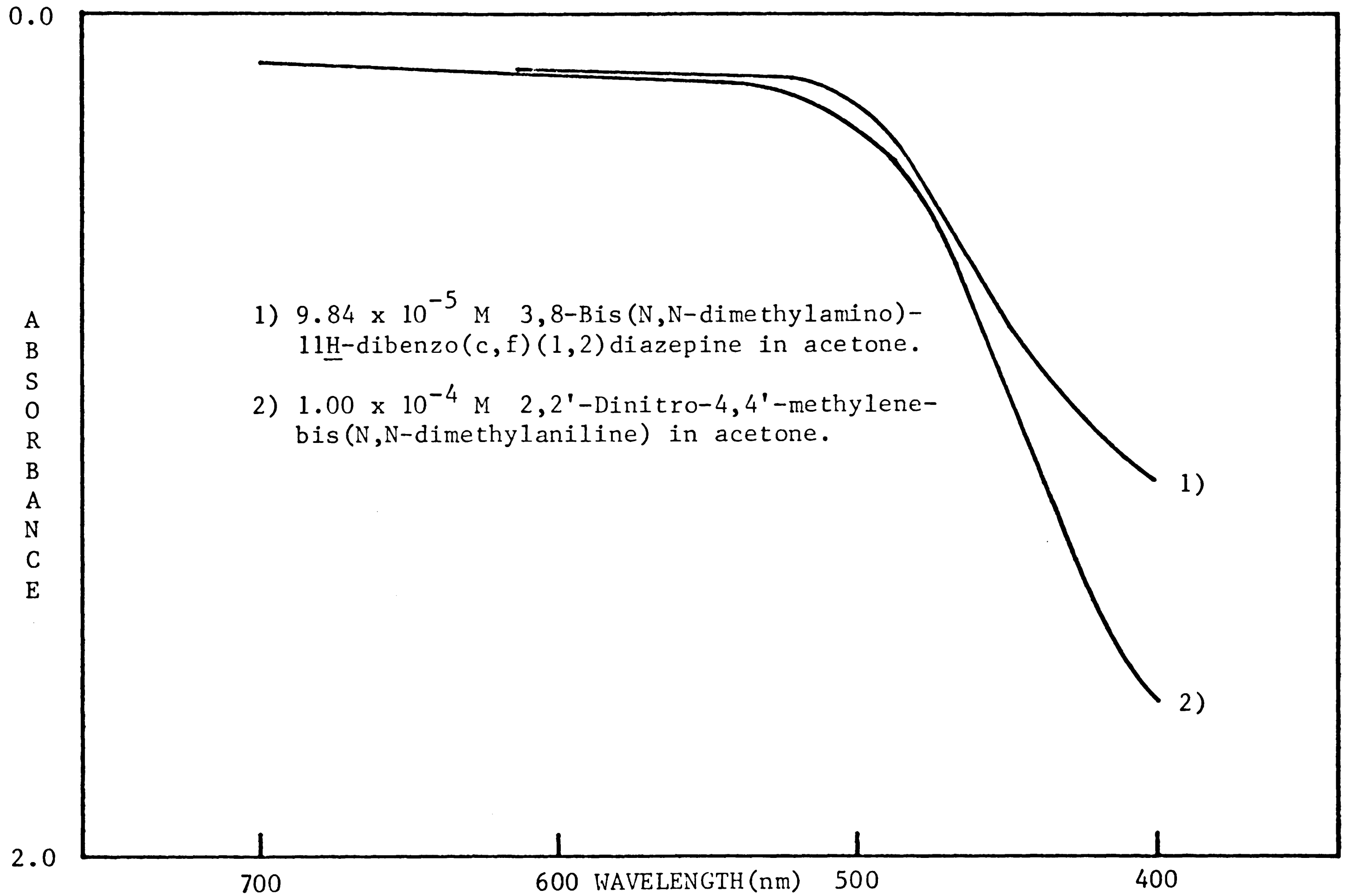


Figure 38 Visible spectra of the dinitro starting material and the diazepine product

Separation of Commercial Dyes

Solutions of 2.30 x 10^{-4} M Orange IV, 2.86 x 10^{-4} M Methyl Green and 8.84 x 10^{-6} M Rose Bengal in methanol were prepared. A 1¼" x 3" column of basic alumina (Brockman Activity I), 80-200 mesh, was slurry packed with a solution of 50 ml water and 50 ml methanol. After this solvent was drained from the column, a mixture of the stock dye solutions was prepared, placed at the head of the column and eluted with 20%, 30% or 40% water-methanol solutions (v/v).

The results of separating a two component dye mixture can be seen in Fig. 39. Three arrays (wavelengths) were monitored during the separation of Methyl Green and Orange IV. The Methyl Green was the first compound eluted, with a characteristic spectrum similar to that in Fig. 40. As can be seen in Fig. 39, Methyl Green absorbs at all three wavelengths monitored. The second component, Orange IV, absorbs at only two of the selected wavelengths. This is consistent with the spectrum of Orange IV seen in Fig. 41.

The separation of a three component mixture consisting of Methyl Green, Orange IV and Rose Bengal can be seen in Fig. 42. Because of a shorter Time Between Spectra, 20 sec versus 30 sec, the peaks appear to be broader. The appearance of the diffuse peak after the Orange IV peak is due to the strongly retained Rose Bengal. Based on these separations, it is easy to envision choosing wavelengths that are specific for one compound.

The separation of green food dye can be seen in Fig. 43. The tailing of the peak may have been due to a high flow rate, too large

Figure 39 Separation of Methyl Green and Orange IV

Separation Conditions

Column	-	Basic alumina, 80-200 mesh 1¼ in x 3 in
Pressure	-	Atmospheric, 14.7 psi
Flow Rate	-	Approximately 5.2 ml/min
Temperature	-	26°
TBS	-	30 sec
ITEG	-	7 msec
Array Numbers	-	16 - bottom trace 104 - middle trace 194 - upper trace
Sweep Frequency	-	50 KHz
Biomation Scale	-	2 V full scale
Solvent System	-	20% H_2O / MeOH (v/v)

Compounds separated: 3.43×10^{-7} mol Methyl Green

1.15×10^{-7} mol Orange IV

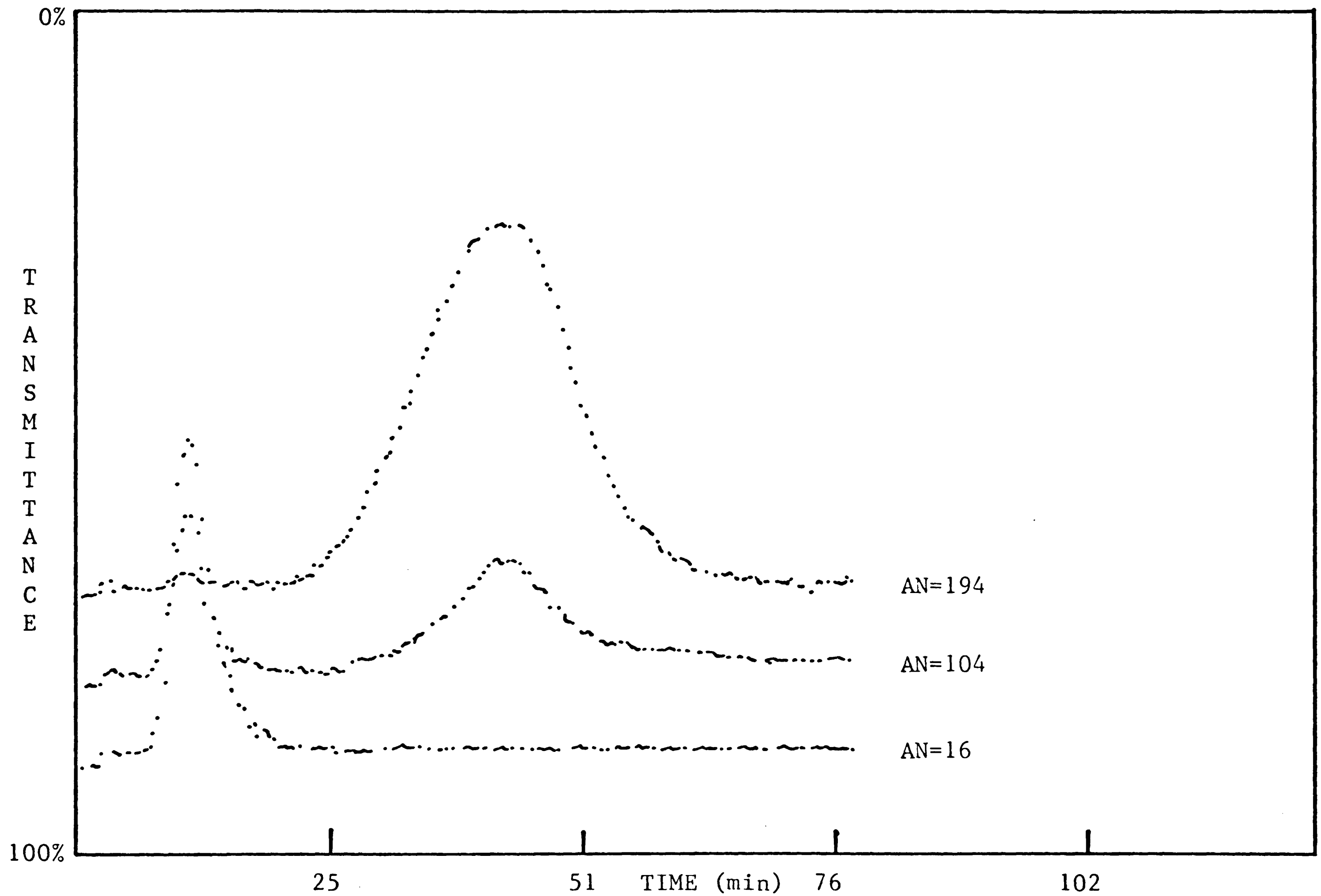


Figure 39 Separation of Methyl Green and Orange IV

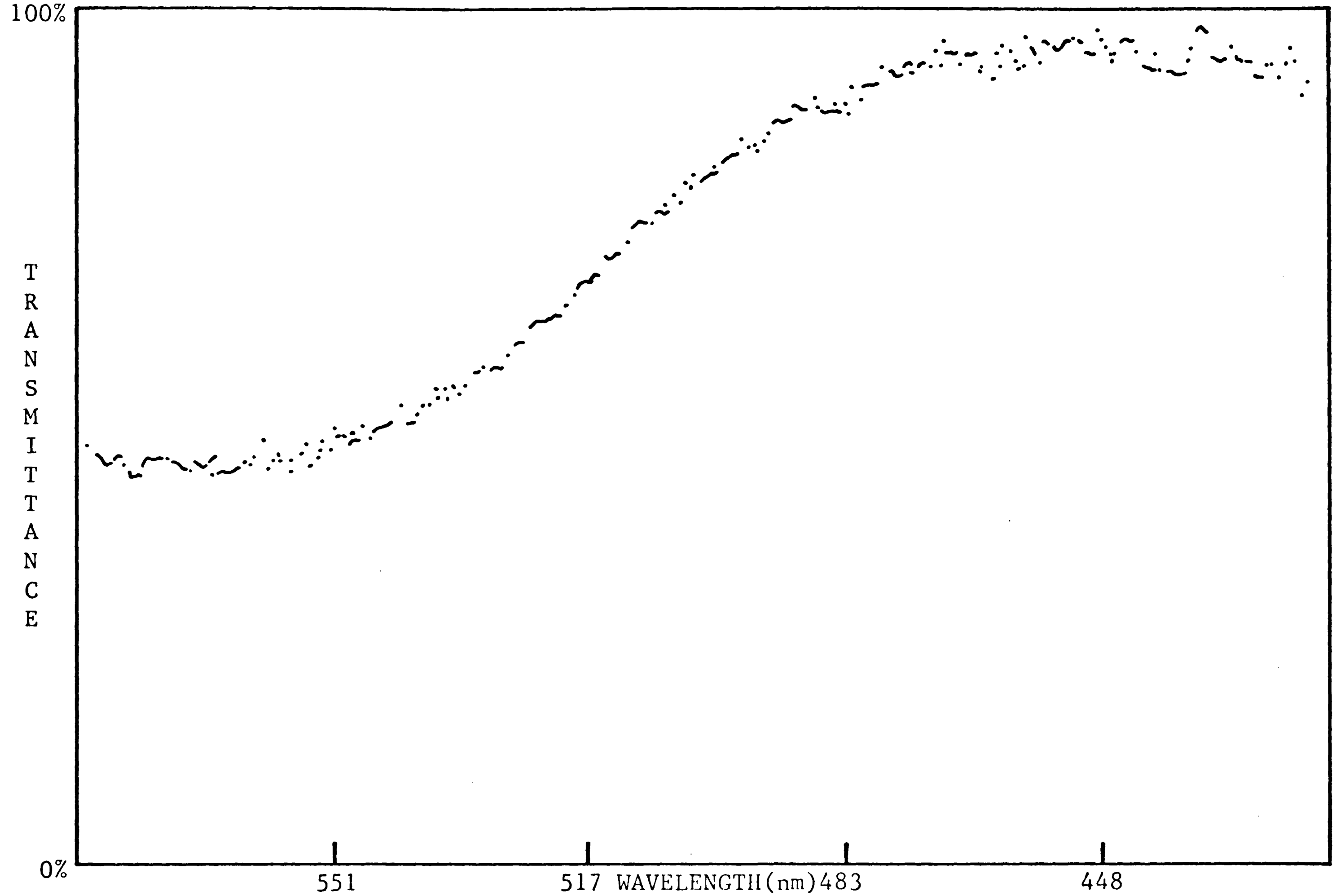


Figure 40 Spectrum Of Methyl Green

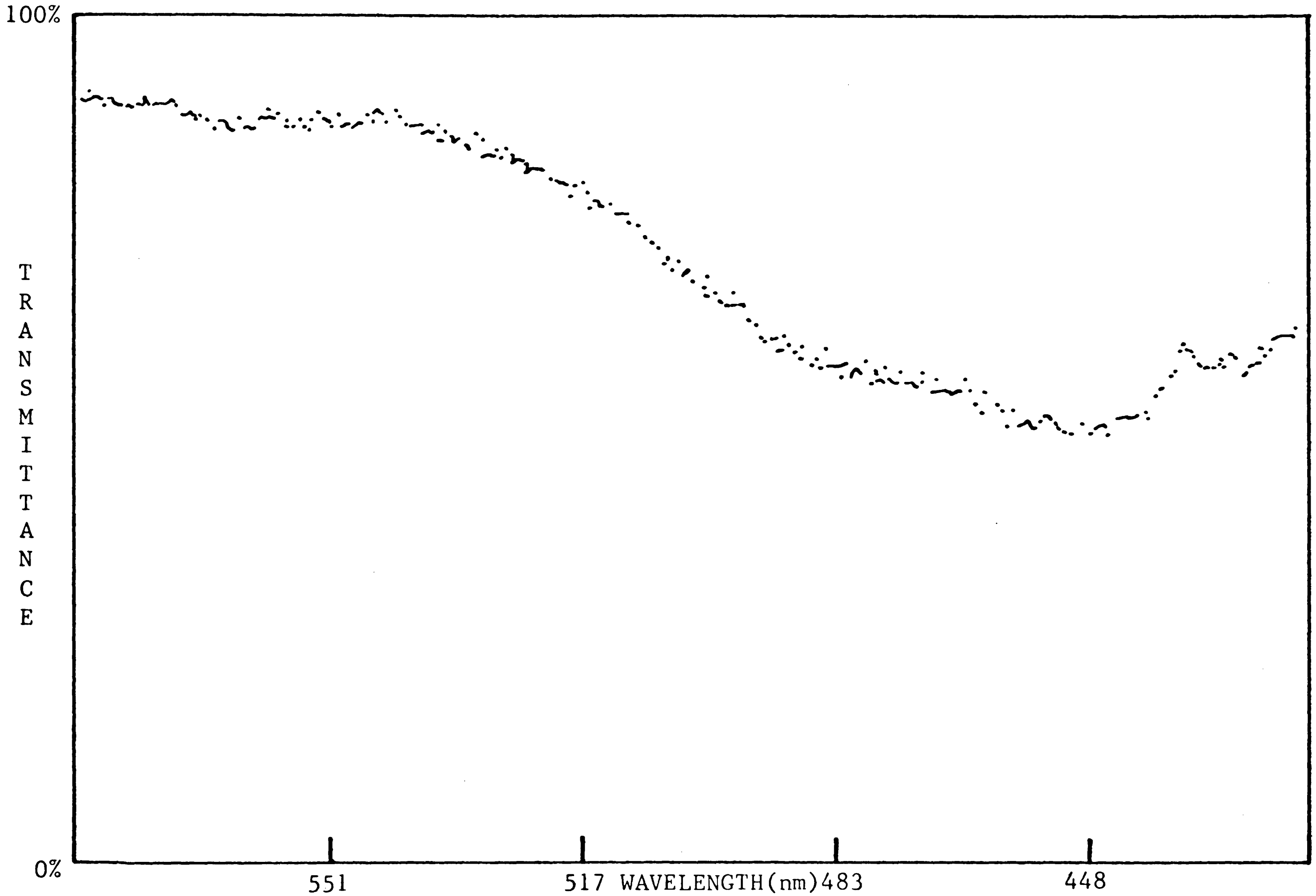


Figure 41 Spectrum of Orange IV

Figure 42 Separation of Methyl Green, Orange IV and Rose Bengal

Separation Conditions

Column	-	Basic alumina, 80-200 mesh 1¼ in x 3 in
Pressure	-	Atmospheric, 14.7 psi
Flow Rate	-	Approximately 5.2 ml/min
Temperature	-	26^{o}
TBS	-	20 sec
ITEG	-	7 msec
Array Numbers	-	16 - lowest trace 59 - next trace up 104 - second highest trace 194 - highest trace
Sweep Frequency	-	50 KHz
Biomation Scale	-	2 V full scale
Solvent System	-	20% H_2O / MeOH (v/v)
Compounds separated:		3.43×10^{-7} mol Methyl Green 2.07×10^{-7} mol Orange IV 7.95×10^{-9} mol Rose Bengal

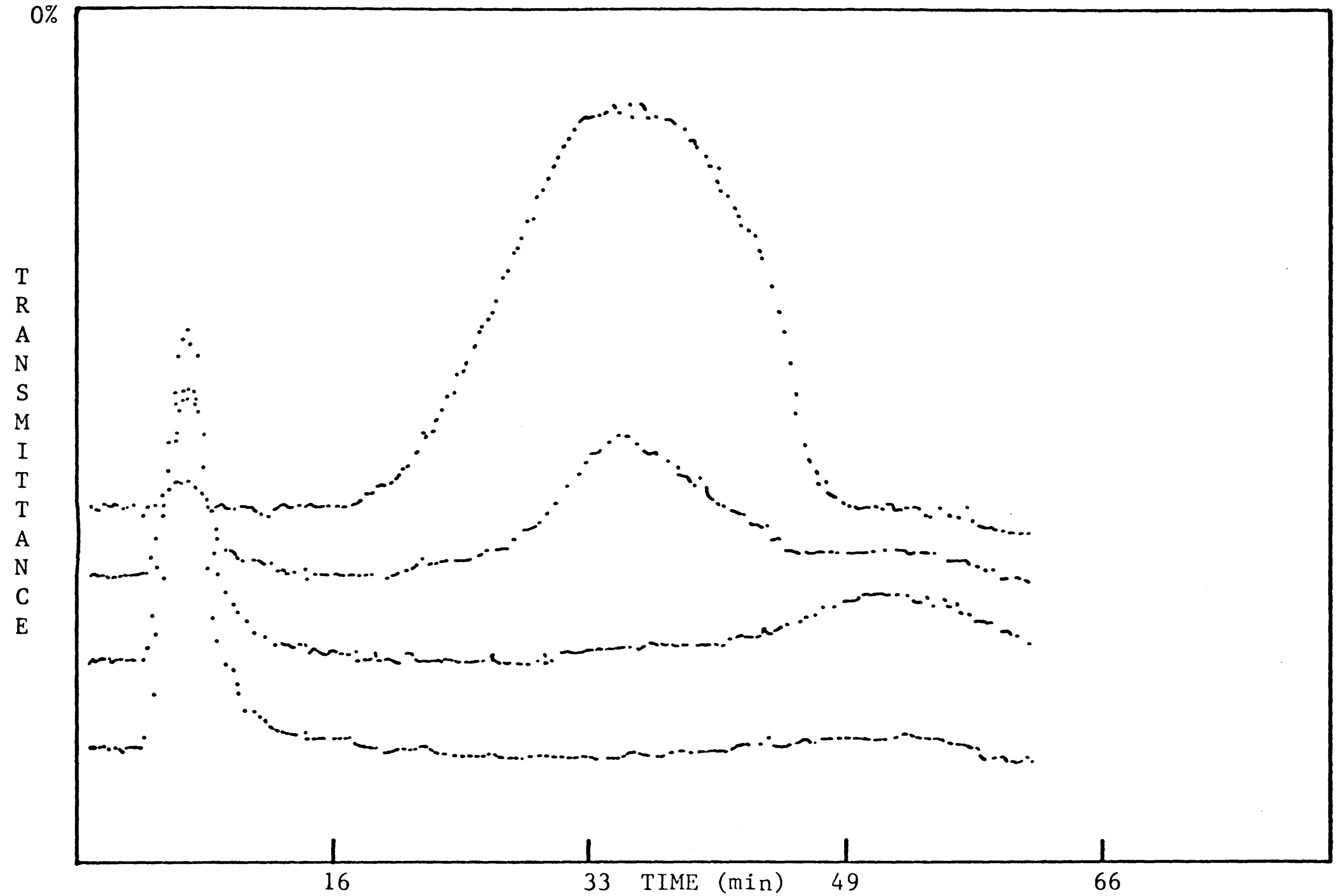


Figure 42   Separation of Methyl Green, Orange IV and Rose Bengal

Figure 43 Absorption of the column effluent at 254 nm produced by chromatographing green food dye

Separation Conditions

Column	-	Basic alumina, 80-200 mesh 6 mm x 19 cm
Pressure	-	20 psi
Flow Rate	-	0.2 ml/min
Temperature	-	25^o
Wavelength	-	254 nm
O.D.	-	2.56
Chart Speed	-	8 in/hr
TBS	-	12 sec
ITEG	-	1 msec
Array Numbers	-	54, 201
Sweep Frequency	-	500 KHz
Biomation Scale	-	2 V full scale
Solvent System	-	Water

Compounds Separated: Green food dye (McCormicks)

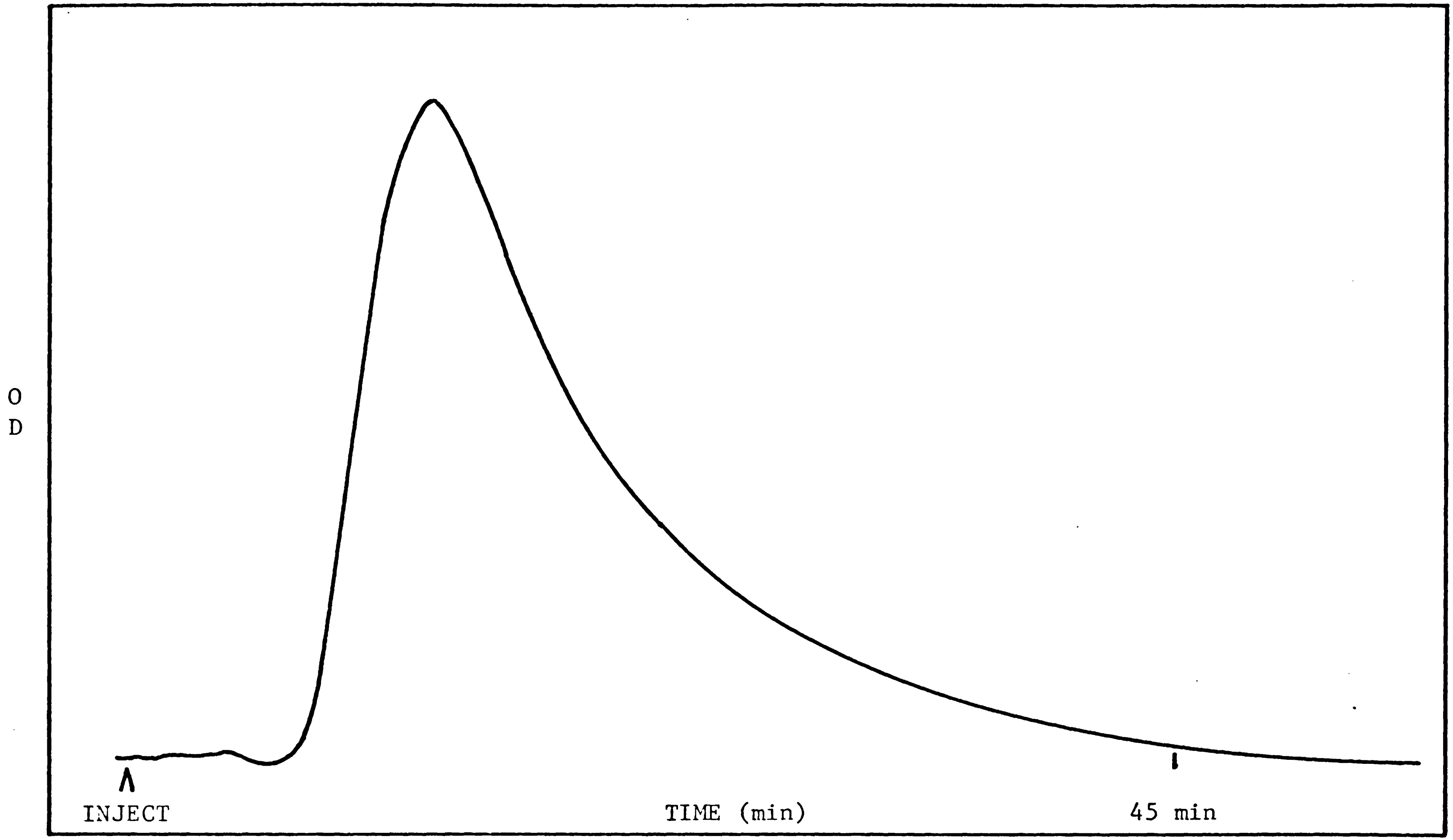


Figure 43 Absorption of the column effluent at 254 nm produced by chromatographing green food dye

a sample or unresolved components. No matter what the cause, another separation would have had to be performed to determine whether or not the tailing was due to unresolved components. At the same time as the absorbance of the column effluent at 254 nm was monitored, the transmittance of the effluent was monitored by the multiwavelength detector. Because the solution was green, array numbers to be monitored were chosen in both the blue and yellow pertions of the visible spectrum.

The same separation produced the plots of Fig. 44 with the multiwavelength detector. Based on these plots, there is little doubt that the green dye consisted of a blue and a yellow component. The blue component was eluted first with tailing and the yellow component second. This demonstrated the utility of the multiwavelength detector for resolving what would normally (with a 254 nm detector) be unresolved components. If desired, the area of at least the yellow peak could have been determined and then compared to standards.

Even if a refractive index detector had been used in conjunction with the 254 nm detector, the identity of the two components could not have been determined, although the refractive index detector would have indicated that the peak was composed of two components.

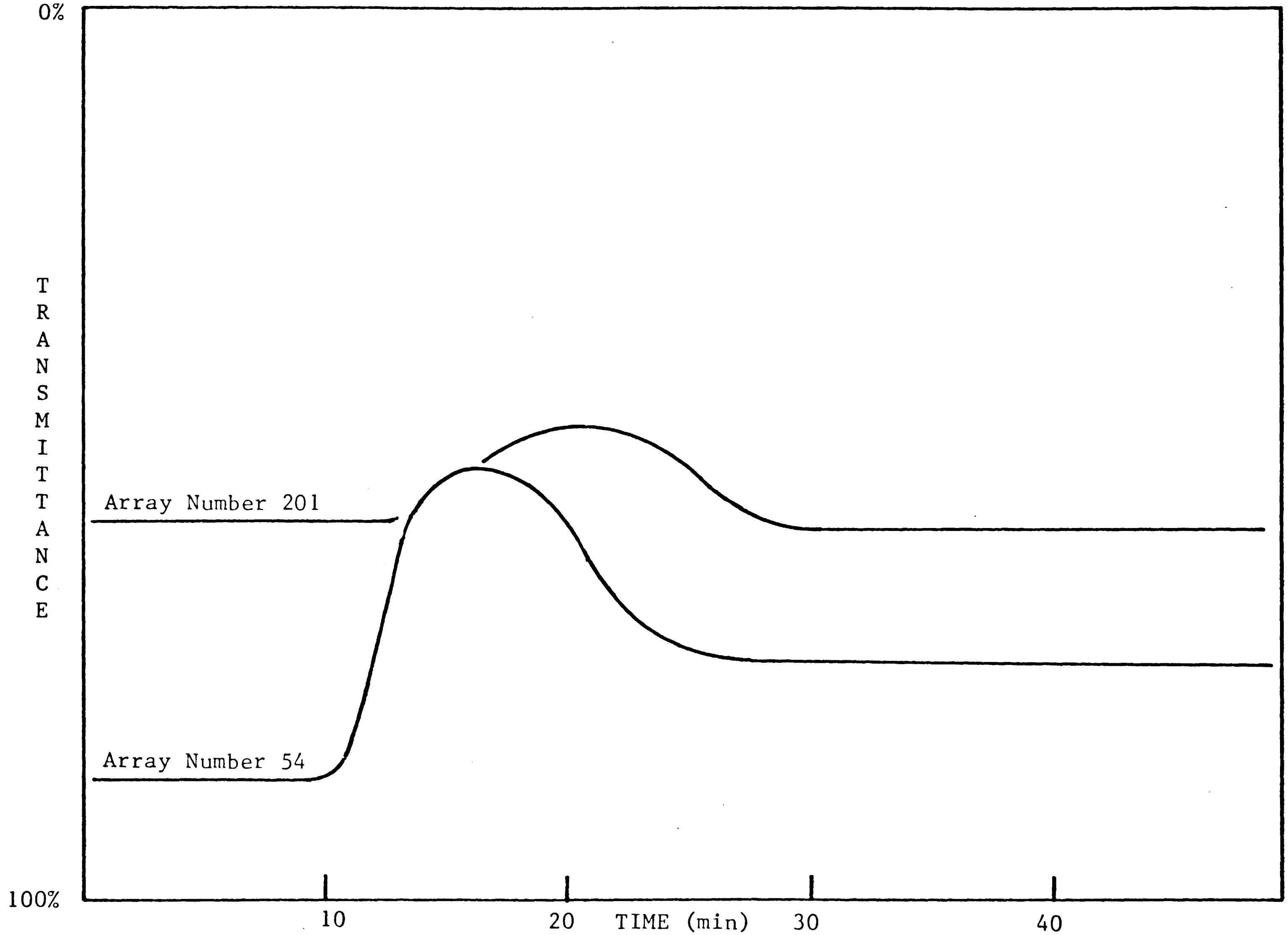


Figure 44 Separation of green food dye

SUMMARY

It has been shown that a microprocessor-based multiwavelength-detector system can be applied to both high and low pressure liquid chromatography. The advantages of using a microprocessor are many and include the following:

With a microprocessor, the experimental conditions can be easily and quickly changed. The Time Between Spectra (TBS), Integration Time (ITEG) and the arrays of interest can all be changed to optimize a separation. With this particular detector system, the separations chemist is no longer limited to monitoring one or two wavelengths.

With reference to the green food dye separation, the computerized detector can produce good results whether or not the components appear to be resolved with a 254 nm detector. Because of the computer's ability to monitor a number of different wavelengths, totally resolved components are not required for producing good spectral data. With the single wavelength detector, components must be resolved to produce useful data.

The computer system is also capable of high data acquisition speeds. The microprocessor can acquire a spectrum of the column effluent in 512 usec or 5.12 msec. Therefore, there is no need to stop the separation, as with most other multiwavelength-detector systems, to obtain a characteristic spectra. Even though the system is capable of these speeds, it can produce spectra comparable with those of a commercial spectrophotometer. Although not implemented in this

system, the computer could have easily integrated the peaks from both the multiwavelength detector and the 254 nm detector.

The detector system was also used to cover a much broader portion of the spectrum than had been previously reported for the linear photodiode arrays. Yet, reasonable resolution was retained. At the same time as the array was characterized in terms of resolution, it was also characterized in terms of sensitivity.

The sensitivity of the detector is perhaps its greatest fault. As was seen in the separation of the nitrobenzene reduction reaction mixture, the single wavelength 254 nm detector detected far smaller concentrations of azobenzene than did the computerized system. This, combined with the fact that the single wavelength detector was set on a very low sensitivity (1.28 or 2.56 O.D.), prevented the multiwavelength-detector system from being applied to many chemical problems. The multiwavelength detector can be used to solve chemical problems, but should be used in conjunction with as many other detectors as possible. If the multiwavelength detector increases the number of data from a particular separation, then it is a useful detector system for liquid chromatography.

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/PAL8 TO 8008 MACRO LOADER   C.A. TITUS   PAL8-V9B  12/09/76  PAGE 1

          /PAL8 TO 8008 MACRO LOADER   C.A. TITUS

          EXPUNGE
     0300 NOOP=300
     0000 HALT=000

     0301 LDAB=301
     0302 LDAC=302
     0303 LDAD=303
     0304 LDAE=304
     0305 LDAH=305
     0306 LDAL=306

     0321 LDCB=321
     0331 LDDB=331
     0341 LDEB=341
     0351 LDHB=351
     0361 LDLB=361

     0310 LDBA=310
     0320 LDCA=320
     0330 LDDA=330
     0340 LDEA=340
     0350 LDHA=350
     0360 LDLA=360
```

```
0312  LDBC=312
0332  LDDC=332
0342  LDEC=342
0352  LDHC=352
0362  LDLC=362

0314  LDBD=314
0324  LDCD=324
0344  LDED=344
0354  LDHD=354
0364  LDLD=364

0315  LDBE=315
0325  LDCE=325
0335  LDDE=335
0355  LDHE=355
0365  LDLE=365

0307  LDAM=307
0317  LDBM=317
0327  LDCM=327
0337  LDDM=337
0347  LDEM=347

0370  LDMA=370
0371  LDMB=371
0372  LDMC=372
0373  LDMD=373
0374  LDME=374
```

```
0300  LDAA=300
0006  LDAI=006
0016  LDBI=016
0026  LDCI=026
0036  LDDI=036
0046  LDEI=046
0056  LDHI=056
0066  LDLI=066
0076  LDMI=076

0315  LDBH=315
0325  LDCH=325
0335  LDDH=335
0365  LDLH=365
0345  LDEH=345

0316  LDBL=316
0326  LDCL=326
0336  LDDL=336
0346  LDEL=346
0356  LDHL=356

0201  ADDB=201
0202  ADDC=202
0203  ADDD=203
```

```
Ø204   ADDE=2Ø4
Ø205   ADDH=2Ø5
Ø206   ADDL=2Ø6
Ø207   ADDM=2Ø7
ØØ04   ADDI=ØØ4

Ø221   SUBB=221
Ø222   SUBC=222
Ø223   SUBD=223
Ø224   SUBE=224
Ø225   SUBH=225
Ø226   SUBL=226
Ø227   SUBM=227
ØØ24   SUBI=Ø24

Ø241   ANDB=241
Ø242   ANDC=242
Ø243   ANDD=243
Ø244   ANDE=244
Ø247   ANDM=247
ØØ44   ANDI=Ø44

Ø271   COMB=271
Ø272   COMC=272
Ø273   COMD=273
Ø274   COME=274
Ø277   COMM=277
Ø275   COMH=275
Ø276   COML=276
```

```
0074   COMI=074

0250   CLRA=250
0250   XORA=250
0251   XORB=251
0252   XORC=252
0253   XORD=253
0254   XORE=254
0255   XORH=255
0256   XORL=256
0257   XORM=257
0054   XORI=054

0260   IORA=260
0261   IORB=261
0262   IORC=262
0263   IORD=263
0264   IORE=264
0265   IORH=265
0266   IORL=266
0267   IORM=267
0064   IORI=064

0010   INCB=010
0020   INCC=020
0030   INCD=030
0040   INCE=040
```

```
ØØ5Ø   INCH=Ø5Ø
ØØ6Ø   INCL=Ø6Ø
ØØ11   DECB=Ø11
ØØ21   DECC=Ø21
ØØ31   DECD=Ø31
ØØ41   DECE=Ø41
ØØ51   DECH=Ø51
ØØ61   DECL=Ø61

ØØØ2   RALT=ØØ2
ØØ12   RART=Ø12
ØØ22   RALC=Ø22
ØØ32   RARC=Ø32

Ø1Ø1   INPØ=1Ø1
Ø1Ø3   INP1=1Ø3
Ø1Ø5   INP2=1Ø5
Ø1Ø7   INP3=1Ø7
Ø111   INP4=111
Ø113   INP5=113
Ø115   INP6=115
Ø117   INP7=117
Ø121   OUTØ=121
Ø123   OUT1=123
Ø125   OUT2=125
Ø127   OUT3=127
Ø131   OUT4=131
Ø133   OUT5=133
```

```
0135    OUT6=135
0137    OUT7=137

0104    JPUN=104
0100    JPFC=100
0110    JPFZ=110
0120    JPFS=120
0140    JPTC=140
0150    JPTZ=150
0160    JPTS=160

0106    JSUN=106
0102    JSFC=102
0112    JSFZ=112
0122    JSFS=122
0142    JSTC=142
0152    JSTZ=152
0162    JSTS=162

0007    RTUN=007
0003    RTFC=003
0013    RTFZ=013
0023    RTFS=023
0043    RTTC=043
0053    RTTZ=053
0063    RTTS=063
```

```
ØØØ5   VECT=ØØ5
ØØØ5   RSTØ=ØØ5
ØØ15   RST1=Ø15
ØØ25   RST2=Ø25
ØØ35   RST3=Ø35
ØØ45   RST4=Ø45
ØØ55   RST5=Ø55
ØØ65   RST6=Ø65
ØØ75   RST7=Ø75

Ø116   LXAM=116
Ø126   LXBM=126
Ø136   LXCM=136
Ø146   LXDM=146
Ø156   LXEM=156
Ø114   LXMA=114
Ø124   LXMB=124
Ø134   LXMC=134
Ø144   LXMD=144
Ø154   LXME=154
Ø237   SBCM=237
Ø217   ADCM=217
Ø3ØØ   LDMM=3ØØ
Ø23Ø   SBCA=23Ø
ØØ34   SBCI=Ø34
       FIXTAB
```

```
                /THIS PROGRAM PERMITS THE USER TO READ PAL8 FORMAT
                /TAPES DIRECTLY INTO AN 8008 MICROPROCESSOR.  IT
                /HAS THE ABILITY TO RECOGNIZE ADDRESS INFORMATION,
                /MACRO (LDRM & LDMR) LOAD INSTRUCTIONS AS WELL AS
                /NON-MACRO LOAD INSTRUCTIONS (LXRM & LXMR).
                /IT ALSO RECOGNIZES IMMEDIATE INSTRUCTIONS AND IN
                /NO WAY TRIES TO INTERPRETE IMMEDIATE DATA AS
                /INSTRUCTIONS. NOTE THAT ERRORS IN LOADING
                /CAN BE CAUSED WHEN ONE OR MORE DATA VALUES ARE
                /ENCOUNTERED.  THE LOADER HAS NO WAY OF KNOWING
                /WHAT IS DATA AND WHAT IS NOT.  VALUES TO
                /AVOID INCLUDE 0X4 AND 0X6.

        0151            RDR=0151        /THIS IS THE TTY READER ROUTINE
        0070            ODT=0070        /THIS IS ODT'S ENTRY POINT
                        FIXTAB

        1400            *1400
01400   0106    START,  JSUN    /GET A PAPER TAPE CHARACTER
01401   0151            RDR
01402   0000            0
01403   0074            COMI
01404   0200            200     /IS IT LEADER ?
```

```
Ø14Ø5  Ø15Ø            JPTZ
Ø14Ø6  14ØØ            START    /YES, GET ANOTHER PAPER TAPE CHARACTER
Ø14Ø7  ØØØØ            Ø
Ø141Ø  Ø1Ø4            JPUN
Ø1411  1423            NOEND    /NOT LEADER, IS IT AN ADDRESS ?
Ø1412  ØØØØ            Ø
Ø1413  Ø1Ø6  NXTCHR,   JSUN
Ø1414  Ø151            RDR      /GET ANOTHER PAPER TAPE CHARACTER
Ø1415  ØØØØ            Ø
Ø1416  ØØ74            COMI
Ø1417  Ø2ØØ            2ØØ      /IS IT TRAILER ?
Ø142Ø  Ø15Ø            JPTZ
Ø1421  ØØ7Ø            ODT      /YES, IT WAS TRAILER, GOTO ODT
Ø1422  ØØØØ            Ø
Ø1423  Ø32Ø  NOEND,    LDCA     /SAVE THE PAPER TAPE CHARACTER
Ø1424  ØØ44            ANDI     /TEST FOR AN ADDRESS
Ø1425  Ø1ØØ            1ØØ
Ø1426  Ø15Ø            JPTZ
Ø1427  1441            DATA     /NOT AN ADDRESS, TREAT IT AS "DATA"
Ø143Ø  ØØØØ            Ø
Ø1431  Ø1Ø6            JSUN     /IT IS AN ADDRESS, SET IT UP AS A
Ø1432  1746            TWOBYT   /FOUR BIT AND EIGHT BIT ADDRESS
Ø1433  ØØØØ            Ø
Ø1434  Ø352            LDHC     /SAVE THE HI BYTE AND THE
Ø1435  Ø365            LDLE     /LO BYTE OF THE ADDRESS
Ø1436  Ø1Ø4            JPUN
Ø1437  1413            NXTCHR   /AND GET ANOTHER PAPER TAPE CHARACTER
Ø144Ø  ØØØØ            Ø
Ø1441  Ø1Ø6  DATA,     JSUN     /NOT AN ADDRESS !
```

```
01442  1453           SING     /WHAT TYPE OF INSTRUCTION IS IT ?
01443  0000           0
01444  0154           LXME     /SAVE IT IN MEMORY
01445  0106           JSUN
01446  1742           INCRHL   /INCREMENT THE MEMORY POINTERS
01447  0000           0
01450  0104           JPUN
01451  1413           NXTCHR   /AND GET ANOTHER PAPER TAPE CHARACTER
01452  0000           0
01453  0106    SING,  JSUN
01454  1746           TWOBYT   /PUT TOGETHER AN EIGHT BIT
01455  0000           0        /BYTE FROM TWO READER FRAMES
01456  0304           LDAE     /CHECK FOR AN INVALID INSTRUCTION
01457  0074           COMI
01460  0130           130      /IS IT AN INVALID JUMP ?
01461  0053           RTTZ     /YES, IT WAS
01462  0074           COMI
01463  0170           170      /IS IT AN INVALID JUMP ?
01464  0053           RTTZ
01465  0074           COMI
01466  0172           172      /IS IT AN INVALID CALL ?
01467  0053           RTTZ     /YES
01470  0074           COMI
01471  0132           132      /IS IT AN INVALID CALL ?
01472  0053           RTTZ     /YES
01473  0074           COMI
01474  0166           166      /THE NEXT FOUR DATA VALUES ARE
```

```
Ø1475  ØØ53        RTTZ     /THE INVALID LXRM AND LXMR
Ø1476  ØØ74        COMI     /INSTRUCTIONS.
Ø1477  Ø176        176
Ø15ØØ  ØØ53        RTTZ
Ø15Ø1  ØØ74        COMI
Ø15Ø2  Ø164        164
Ø15Ø3  ØØ53        RTTZ
Ø15Ø4  ØØ74        COMI
Ø15Ø5  Ø174        174
Ø15Ø6  ØØ53        RTTZ
Ø15Ø7  ØØ74        COMI
Ø151Ø  Ø1Ø4        1Ø4      /IF A JUMP IS ENCOUNTERED, AN
Ø1511  Ø15Ø        JPTZ     /ADDRESS (4 FRAMES) FOLLOWS.
Ø1512  17Ø1        JUMP
Ø1513  ØØØØ        Ø
Ø1514  ØØ74        COMI
Ø1515  Ø1Ø6        1Ø6      /UNCONDITIONAL CALL ?
Ø1516  Ø15Ø        JPTZ
Ø1517  17Ø1        JUMP
Ø152Ø  ØØØØ        Ø
Ø1521  ØØ44        ANDI
Ø1522  Ø3Ø7        3Ø7      /MASK OUT THE 3 MIDDLE BITS
Ø1523  ØØ74        COMI
Ø1524  ØØØ6        ØØ6      /IS IT A LOAD IMMEDIATE (ØX6)
Ø1525  Ø15Ø        JPTZ
Ø1526  1726        IMMED    /YES
Ø1527  ØØØØ        Ø
Ø153Ø  ØØ74        COMI
```

```
01531  0004         004     /AN IMMEDIATE ALU INSTRUCTION ?
01532  0150         JPTZ
01533  1726         IMMED   /YES
01534  0000         0
01535  0074         COMI
01536  0100         100     /A CONDITIONAL JUMP ?
01537  0150         JPTZ
01540  1701         JUMP    /YES
01541  0000         0
01542  0074         COMI
01543  0102         102     /A CONDITIONAL CALL ?
01544  0150         JPTZ
01545  1701         JUMP    /YES
01546  0000         0
01547  0074         COMI
01550  0307         307     /IS IT A LDMX ?
01551  0150         JPTZ
01552  1621         LOADER  /YES
01553  0000         0
01554  0074         COMI
01555  0106         106     /NO, IS IT A LXRM ?
01556  0150         JPTZ
01557  1577         FAKE1   /YES
01560  0000         0
01561  0074         COMI
01562  0104         104     /NO, IS IT A LXMR ?
```

```
Ø1563  Ø15Ø            JPTZ
Ø1564  16Ø4            FAKE2    /YES
Ø1565  ØØØØ            Ø
Ø1566  Ø3Ø4            LDAE     /GET THE CHARACTER BACK AGAIN
Ø1567  ØØ44            ANDI
Ø157Ø  Ø37Ø            37Ø      /MASK OUT THE 3 LSB'S
Ø1571  ØØ74            COMI
Ø1572  Ø37Ø            37Ø      /IS IT A LDMX INSTRUCTION ?
Ø1573  Ø15Ø            JPTZ
Ø1574  1621            LOADER
Ø1575  ØØØØ            Ø
Ø1576  ØØØ7            RTUN     /IT WASN'T ANY OF THESE SPECIAL
                                /INSTRUCTIONS, SO WE DON'T PERFORM
                                /ANY SPECIAL OPERATIONS

Ø1577  Ø3Ø4   FAKE1,   LDAE     /THIS IS USED BY THE
Ø16ØØ  ØØØ4            ADDI     /LXRM INSTRUCTIONS
Ø16Ø1  Ø171            171      /THIS CONVERTS THE 1X6 TO A 3X7
Ø16Ø2  Ø34Ø   SAVFK,   LDEA     /PUT IT BACK IN E
Ø16Ø3  ØØØ7            RTUN

Ø16Ø4  Ø3Ø4   FAKE2,   LDAE     /THIS IS FOR THE LXMR INSTRUCTIONS
Ø16Ø5  ØØ44            ANDI     /(NON-MACRO)
Ø16Ø6  ØØ7Ø            Ø7Ø      /GET THE REGISTER DESTINATION
Ø16Ø7  ØØ24            SUBI     /THIS IS DUE TO THE
Ø161Ø  ØØ1Ø            Ø1Ø      /INSTRUCTION DEFINITION
Ø1611  ØØ12            RART
Ø1612  ØØ12            RART
Ø1613  ØØ12            RART     /GET IT TO THE SOURCE POSITION
```

```
01614  0004              ADDI     /ADD THE LDMX INSTRUCTION
01615  0370              370
01616  0104              JPUN     /NOW SAVE IT IN E
01617  1602              SAVFK
01620  0000              0

                 /THE LOADER SUBROUTINE IS FOR THE MACRO LOADS.
                 /IT WILL DETERMINE THE HI AND LO ADDRESS FROM
                 /THE PDP-8'S 12 BIT ADDRESS AND LOAD INTO MEMORY
                 /THE LDHI & LDLI INSTRUCTIONS ALONG WITH THE
                 /APPROPRIATE ADDRESS INFORMATION AND THEN FINALLY,
                 /THE ACTUAL MEMORY REFERENCE INSTRUCTION.

01621  0315     LOADER,  LDBE     /SAVE THE ACTUAL LOAD INSTRUCTION
01622  0106              JSUN
01623  0151              RDR      /GET PART OF THE 12 BIT ADDRESS
01624  0000              0
01625  0320              LDCA     /SAVE IT IN C FOR TWOBYT
01626  0106              JSUN
01627  1746              TWOBYT   /EXIT WITH C=HI & E=LO
01630  0000              0
01631  0302              LDAC
01632  0074              COMI     /IS THE NEXT WORD = 000 ? IF IT IS
01633  0000              000      /WE HAVE DATA AND NOT
01634  0110              JPFZ     /ADDRESS INFORMATION
01635  1644              LOADOK
01636  0000              0
```

```
01637  0124          LXMB    /SAVE THE DATA WORD
01640  0106          JSUN
01641  1742          INCRHL  /INCREMENT THE H&L POINTERS
01642  0000          0
01643  0007          RTUN

               /WHEN A MACRO LOAD INSTRUCTION IS
               /ENCOUNTERED, WE COME HERE.

01644  0076  LOADOK, LDMI
01645  0056          056     /SAVE THE LDHI INSTRUCTION
01646  0106          JSUN
01647  1742          INCRHL
01650  0000          0
01651  0134          LXMC    /AND THEN THE HI ADDRESS
01652  0106          JSUN
01653  1742          INCRHL
01654  0000          0
01655  0076          LDMI
01656  0066          066     /SAVE THE LDLI INSTRUCTION
01657  0106          JSUN
01660  1742          INCRHL
01661  0000          0
01662  0154          LXME    /AND THEN THE LO ADDRESS
01663  0106          JSUN
01664  1742          INCRHL
01665  0000          0
01666  0341          LDEB    /SET E = TO THE ACTUAL INSTRUCTION
```

```
Ø1667  ØØ26          LDCI
Ø167Ø  ØØØ6          ØØ6      /THIS IS THE NUMBER OF "Ø" FRAMES
Ø1671  Ø1Ø6  SKIP3,  JSUN     /TO SKIP OVER ON THE PAPER TAPE
Ø1672  Ø151          RDR
Ø1673  ØØØØ          Ø
Ø1674  ØØ21          DECC     /C=THE NUMBER OF FRAMES TO SKIP
Ø1675  Ø11Ø          JPFZ
Ø1676  1671          SKIP3
Ø1677  ØØØØ          Ø
Ø17ØØ  ØØØ7          RTUN     /INSTRUCTION IS STILL IN E.

             /IF WE HAD ENCOUNTERED ANY TYPE OF JUMP OR CALL
             /INSTRUCTION, BOTH CONDITIONAL OR UNCONDITIONAL,
             /WE WOULD COME HERE TO BREAK UP THE 12 BIT PDP-8
             /ADDRESS INTO A HI & LO ADDRESS.

Ø17Ø1  Ø154  JUMP,   LXME     /SAVE THE JUMP OR CALL INSTRUCTION
Ø17Ø2  Ø1Ø6          JSUN
Ø17Ø3  1742          INCRHL
Ø17Ø4  ØØØØ          Ø
Ø17Ø5  Ø1Ø6          JSUN     /NOW GET PART OF THE ADDRESS
Ø17Ø6  Ø151          RDR
Ø17Ø7  ØØØØ          Ø
Ø171Ø  Ø32Ø          LDCA
Ø1711  Ø1Ø6          JSUN
Ø1712  1746          TWOBYT   /DETERMINE THE HI AND LO ADDRESS
Ø1713  ØØØØ          Ø
```

```
Ø1714  Ø154        LXME    /SAVE THE LO ADDRESS
Ø1715  Ø1Ø6        JSUN
Ø1716  1742        INCRHL
Ø1717  ØØØØ        Ø
Ø172Ø  Ø342        LDEC    /PUT THE HI ADDRESS IN "E"
Ø1721  ØØ26        LDCI    /WE HAVE TO SKIP OVER 2 FRAMES
Ø1722  ØØØ2        ØØ2     /OF "Ø".
Ø1723  Ø1Ø4        JPUN
Ø1724  1671        SKIP3
Ø1725  ØØØØ        Ø
```

```
                  /IF ANY TYPE OF IMMEDIATE INSTRUCTION IS
                  /ENCOUNTERED, WE COME HERE TO DETERMINE THE
                  /CORRECT DATA VALUE TO BE LOADED IN MEMORY
                  /AFTER THE ACTUAL IMMEDIATE INSTRUCTION.


Ø1726  Ø154  IMMED,  LXME      /SAVE THE IMMEDIATE INSTRUCTION
Ø1727  Ø1Ø6          JSUN
Ø173Ø  1742          INCRHL
Ø1731  ØØØØ          Ø
Ø1732  Ø1Ø6          JSUN
Ø1733  Ø151          RDR       /GET PART OF THE DATA VALUE
Ø1734  ØØØØ          Ø
Ø1735  Ø32Ø          LDCA      /SET IT UP FOR TWOBYT
Ø1736  Ø1Ø6          JSUN
Ø1737  1746          TWOBYT
Ø174Ø  ØØØØ          Ø
Ø1741  ØØØ7          RTUN      /ON RETURNING, WE SAVE E IN MEMORY !

                  /THIS IS THE SUBROUTINE THAT INCREMENTS THE
                  /LO ADDRESS AND THEN INCREMENTS THE HI ADDRESS
                  /IF APPROPRIATE.

Ø1742  ØØ6Ø  INCRHL, INCL
Ø1743  ØØ53          RTTZ
```

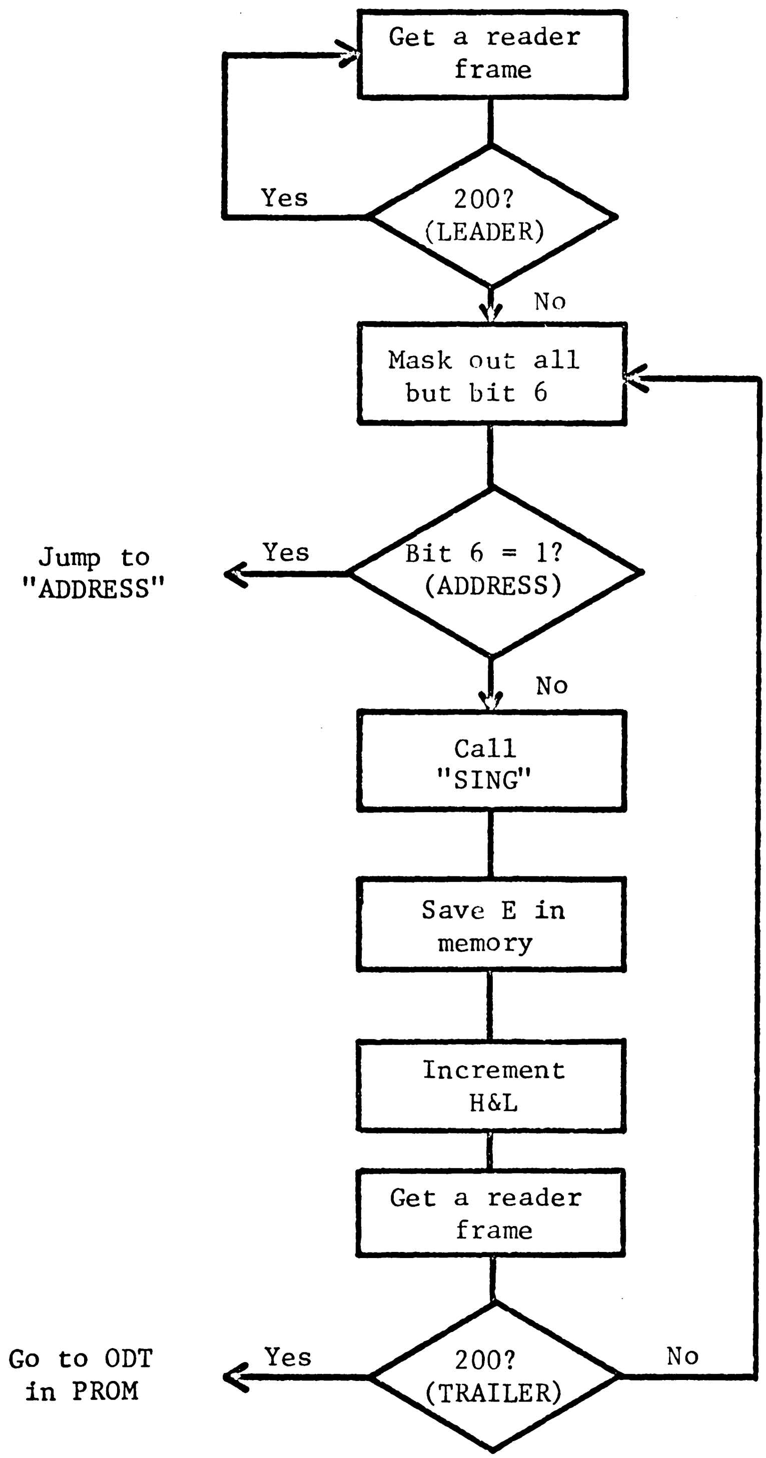
```
Ø1744  ØØ5Ø          INCH
Ø1745  ØØØ7          RTUN

Ø1746  Ø1Ø6  TWOBYT, JSUN    /THIS PACKS TWO PAPER TAPE FRAME INTO
Ø1747  Ø151          RDR     /ONE OR TWO - EIGHT BIT WORDS.
Ø175Ø  ØØØØ          Ø
Ø1751  Ø34Ø          LDEA    /SAVE THE SECOND FRAME
Ø1752  Ø3Ø2          LDAC    /GET THE FIRST FRAME
Ø1753  ØØ44          ANDI    /SAVE THE TWO LEAST SIGNIFICANT BITS
Ø1754  ØØØ3          ØØ3
Ø1755  ØØ12          RART    /ROTATE THEM INTO THE
Ø1756  ØØ12          RART    /MOST SIGNIFICANT BITS
Ø1757  Ø2Ø4          ADDE    /ADD THE SIX BIT VALUE IN E
Ø176Ø  Ø34Ø          LDEA    /SAVE THE EIGHT BIT VALUE IN E
Ø1761  Ø3Ø2          LDAC    /GET THE FIRST FRAME AGAIN
Ø1762  ØØ44          ANDI    /SAVE ALL BUT THE TWO LEAST
Ø1763  ØØ74          Ø74     /SIGNIFICANT BITS
Ø1764  ØØ12          RART    /ROTATE THEM INTO THE LEAST
Ø1765  ØØ12          RART    /SIGNIFICANT BIT POSITIONS
Ø1766  Ø32Ø          LDCA    /AND SAVE THE FOUR BIT VALUE
Ø1767  ØØØ7          RTUN    /C=MSB, E=LSB
                     $
```

```
DATA    1441
FAKE1   1577
FAKE2   1604
IMMED   1726
INCRHL  1742
JUMP    1701
LOADER  1621
LOADOK  1644
NOEND   1423
NXTCHR  1413
SAVFK   1602
SING    1453
SKIP3   1671
START   1400
TWOBYT  1746
```

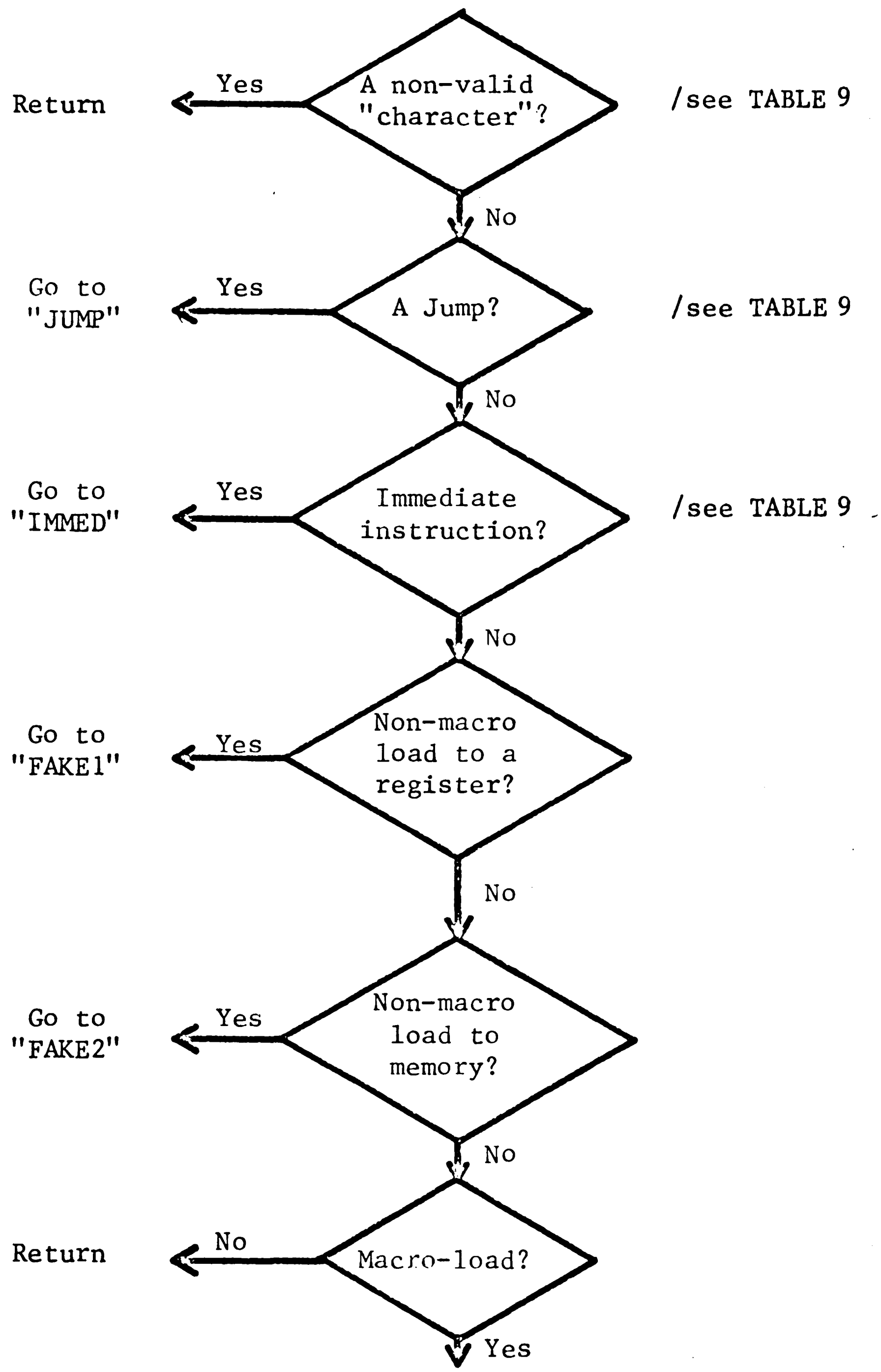
APPENDIX B

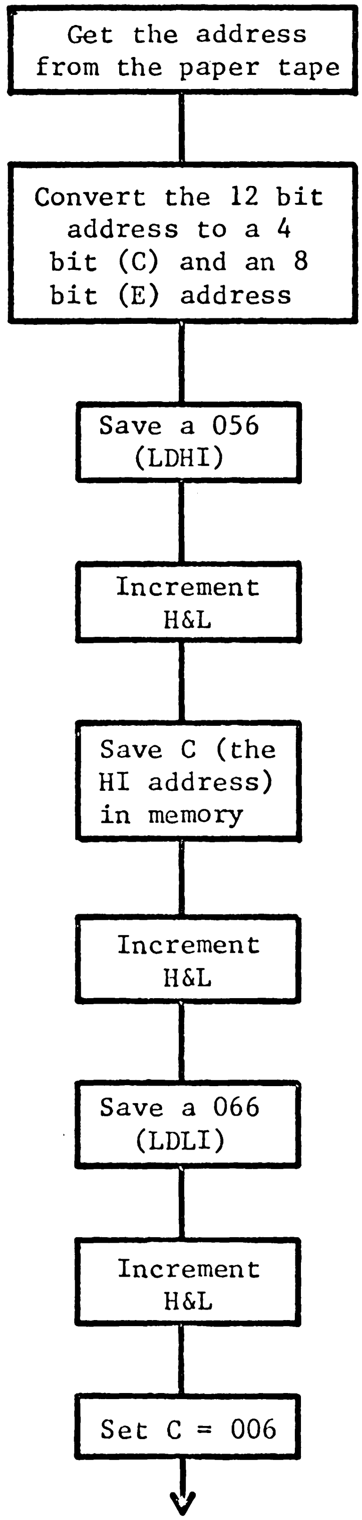
PAL8 to 8008 MACRO LOADER

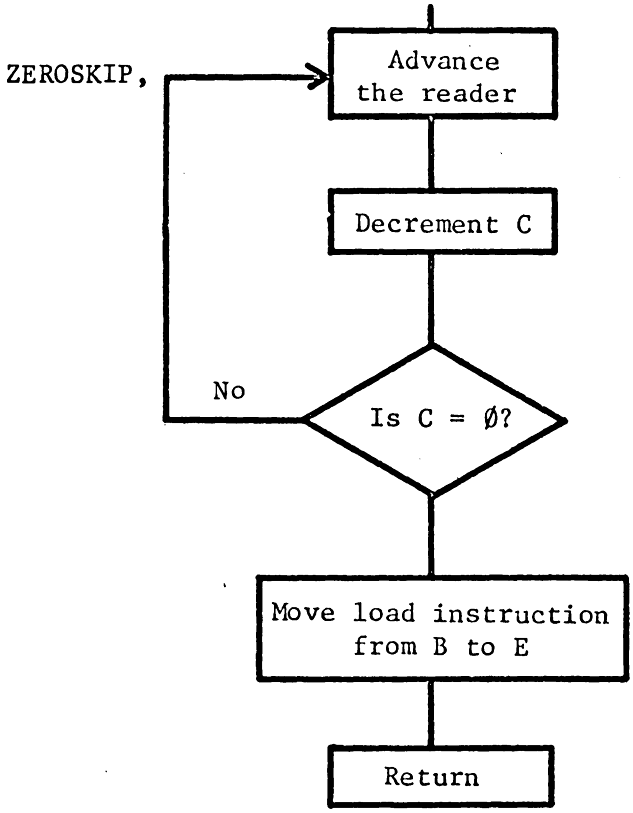


SING

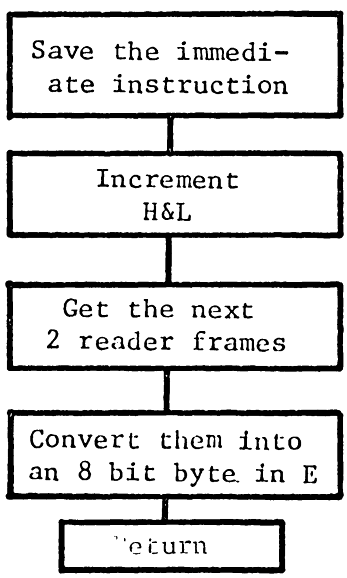
This is the heart of the loader program. It determines whether a jump, immediate or macro load instruction has been read from the paper tape, and takes the appropriate action on successive paper tape frames before exiting.




Get the address from the paper tape
Convert the 12 bit address to a 4 bit (C) and an 8 bit (E) address
Save a 056 (LDHI)
Increment H&L
Save C (the HI address) in memory
Increment H&L
Save a 066 (LDLI)
Increment H&L
Set C = 006

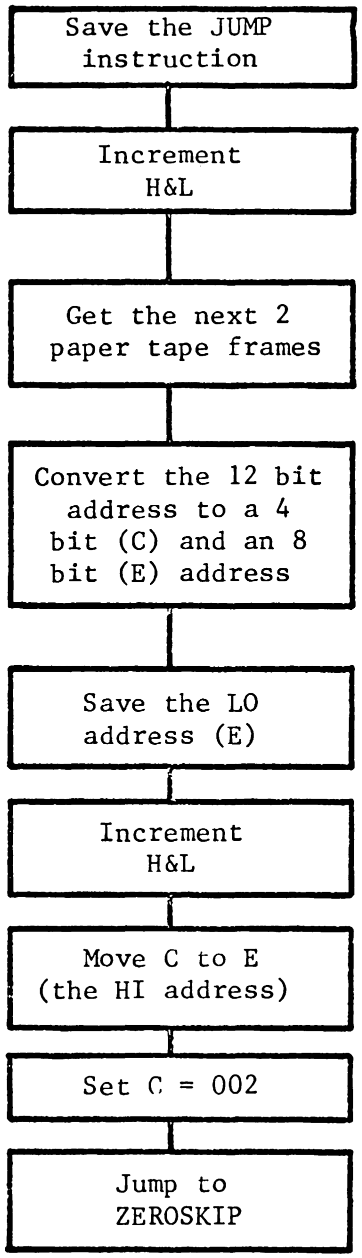

ZEROSKIP,
Advance the reader
Decrement C
No
Is C = Ø?
Move load instruction from B to E
Return

IMMED

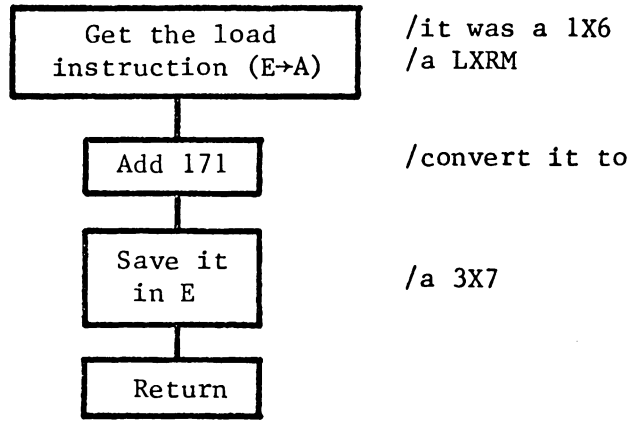

Save the immediate instruction
Increment H&L
Get the next 2 reader frames
Convert them into an 8 bit byte in E

JUMP

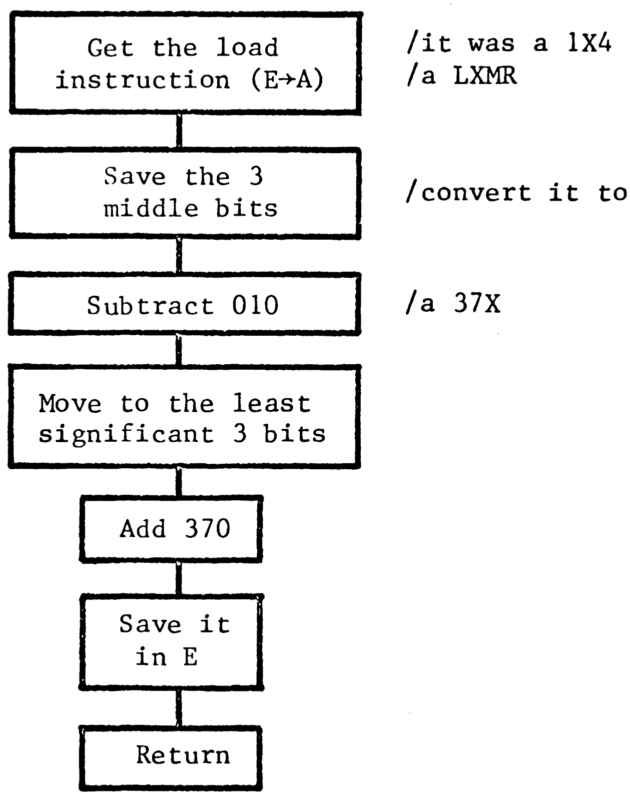
This subroutine is used anytime any type of jump or call is encountered.



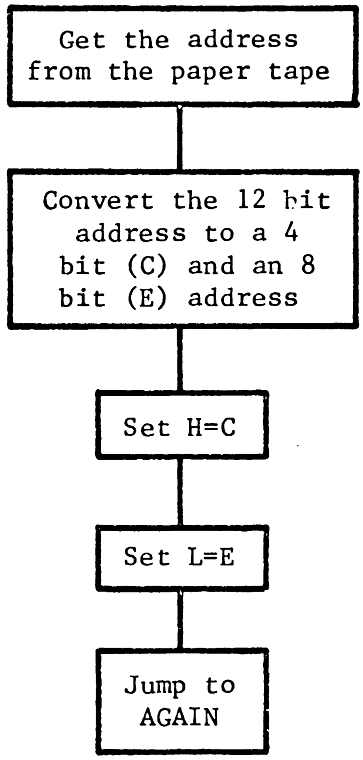
FAKE 1


Get the load instruction (E→A)
/it was a 1X6
/a LXRM
Add 171
/convert it to
Save it in E
/a 3X7
Return

FAKE 2


Get the load instruction (E→A)
/it was a 1X4
/a LXMR
Save the 3 middle bits
/convert it to
Subtract 010
/a 37X
Move to the least significant 3 bits
Add 370
Save it in E
Return

ADDRESS,



Get the address from the paper tape
Convert the 12 bit address to a 4 bit (C) and an 8 bit (E) address
Set H=C
Set L=E
Jump to AGAIN

TABLE 9

SPECIAL MACRO LOADER OCTAL CODES

Non-valid Characters:

130 - Non-valid jump - treat as data
170 - Non-valid jump - treat as data
132 - Non-valid call - treat as data
172 - Non-valid call - treat as data

166 - Non-valid LXHM
176 - Non-valid LXLM
164 - Non-valid LXMH
174 - Non-valid LXML

A "jump" is considered one of the following:

104 - unconditional jump
106 - unconditional call
1X0 - conditional jump
1X2 - conditional call

An "immediate" includes immediate load and math instructions

0X6 - immediate load
0X4 - immediate math

```
0171          DS=171  /THESE ARE 8008 OUTPUT CODES
0173          IOP1=173
0175          IOP2=175
0177          IOP3=177
0040          RTC40=040        /THESE ARE THE DATA VALUES
0041          BI041=041        /TO BE LATCHED OUT FOR THE
0042          RET42=042        /DS-IOP COMMANDS
0043          PLTENB=043
0044          PEN44=044
0047          BUFF47=047

0115          SR1=115 /THESE ARE INPUT SENSE REGISTERS
0117          SR2=117

0200          DATRDY=200       /BITS OF A SENSE REGISTER
0100          RTCRDY=100
0001          NE555=001

0113          READ=113         /INPUT THE BIOMATION DATA
0133          LRTCB=133        /LOAD THE REAL TIME CLOCK BUFFER
0137          XDAC=137
0135          YDAC=135

0070          ODT=070

              FIXTAB
```

```
        4010            *4010
04010   0106   BASE,    JSUN     /GET A SPECTRA
04011   5150            RETCON
04012   0000            0
04013   0104            JPUN     /ARE WE OFF SCALE ?
04014   3050            CHKIT
04015   0000            0
04016   0106   DATOK,   JSUN     /DETERMINE THE BASELINE
04017   3246            BASEC    /CORRECTION CONSTANTS
04020   0000            0
04021   0106   SCALE,   JSUN     /MULTIPLY THE BASELINE BY THE
04022   3350            DATCRT   /BASELINE CORRECTION CONSTANTS
04023   0000            0        /AND SEE WHAT HAPPENS
04024   0106            JSUN     /DISPLAY THE RESULTS
04025   5113            DISPLA
04026   0000            0
04027   0007            RTUN
04030   0000   HIP,     000      /COMPLETE SPECTRA MEMORY POINTER

        4032            *4032
04032   0010   NUMBSA,  010      /THESE ARE SCRATCH LOCATIONS
04033   0000   DATAT,   000
04034   0000   MASK,    000
04035   0000   DATPNT,  000
04036   0000   BASPNT,  000
04037   0015            015

        4040            *4040
```

```
04040  0000  TEMPD,  0        /THESE 3 LOCATIONS ARE USED
04041  0000          0        /BY THE MULTIPLY & DIVIDE
04042  0000          0        /ROUTINES.
04043  0006  SRTC,   LDAI     /STOP THE REAL TIME CLOCK
04044  0040          040
04045  0171          DS
04046  0177          IOP3
04047  0106          JSUN     /PUNCH OUT SOME TRAILER
04050  3034          LDTR
04051  0000          0
04052  0104          JPUN     /GO BACK TO THE EXECUTIVE
04053  2400          NXTCMD
04054  0000          0

       4060          *4060
04060  0104  GETSPC, JPUN     /INTERRUPT SERVICE SUBROUTINE
04061  5026          INT1
04062  0000          0
       4077          *4077
04077  0000  TBSM,   000      /TBS IS STORED HERE
04100  0000  C0,     000      /ALL OF OUR COMPRESSED DATA VALUES
04101  0000  C1,     000      /ARE STORED IN THESE CONSECUTIVE
04102  0000  C2,     000      /MEMORY LOCATIONS.
04103  0000  C3,     000
04104  0000  C4,     000
04105  0000  C5,     000
04106  0000  C6,     000
04107  0000  C7,     000
```

```
04110   0106   SPECTR, JSUN     /THE "Z" COMMAND GOT US HERE
04111   4520           PNUP
04112   0000           0
04113   0006           LDAI     /THIS IS THE POINTER FOR STORING
04114   0021           021      /COMPLETE SPECTRA. WE CAN STORE
04115   0370           LDMA     /NO MORE THAN 3.  THE 021 IS THE
04116   4030           HIP      /HI ADDRESS FOR THE FIRST SPECTRA
04117   0000           0        /FROM LO = 000 TO 377.
04120   0000           0
04121   0000           0
04122   0106           JSUN
04123   5667           CLEAN
04124   0000           0
04125   0370           LDMA
04126   5575           XPOS     /XPOS=000 THIS IS THE X
04127   0000           0        /COORDINATE USED IN PLOTTING
04130   0000           0
04131   0000           0
04132   0137           XDAC
04133   0135           YDAC
04134   0106           JSUN     /TBS:   (TYPED OUT)
04135   5343           LISTER
04136   0000           0
04137   0106           JSUN     /INPUT A DECIMAL NUMBER
04140   4525           INPUT
04141   0000           0
04142   0302           LDAC     /A=BINARY NUMBER
```

```
04143  0056        LDHI
04144  0010        010
04145  0066        LDLI
04146  0077        077
04147  0114        LXMA      /SAVE TBS IN 010 077.
04150  0024        SUBI
04151  0001        001       /LRTCB WITH 1 LESS THAN SPECIFIED
04152  0133        LRTCB
04153  0026        LDCI
04154  0377        377
04155  0372        LDMC
04156  5675        NMSPC
04157  0000        0
04160  0000        0
04161  0000        0
04162  0106        JSUN
04163  5343        LISTER    /ITEG. TIME:
04164  0000        0
04165  0106        JSUN      /INPUT A DECIMAL NUMBER
04166  4525        INPUT
04167  0000        0
04170  0372        LDMC
04171  5200        ITIME
04172  0000        0
04173  0000        0
04174  0000        0
```

```
04175  0106  ARRY,   JSUN
04176  5343          LISTER   /ARE ARRAY #'S KNOWN ?
04177  0000          0
04200  0106          JSUN
04201  5667          CLEAN
04202  0000          0
04203  0307          LDAM     /SET H&L TO POINT TO ARRAY # TABLE.
04204  5676          PNT1
04205  0000          0
04206  0000          0
04207  0000          0
04210  0106          JSUN
04211  3120          TTYIN    /GET A TTY CHARACTER
04212  0000          0
04213  0074          COMI     /IS IT A Y OR N ?
04214  0331          331      /A Y ?, IF SO, JUST INPUT THE ARRAY #'S
04215  0150          JPTZ
04216  4226          DATA
04217  0000          0
04220  0106          JSUN     /NOT Y, EXECUTE THE
04221  6071          CURSE    /CURSOR ROUTINES
04222  0000          0
04223  0104          JPUN
04224  4270          CALIB
04225  0000          0
04226  0106  DATA,   JSUN     /ANSWERED Y FOR YES,
04227  4525          INPUT    /INPUT ARRAY #'S
04230  0000          0
04231  0074          COMI     /A CR TERMINATOR ?
```

```
04232  0215           215
04233  0150           JPTZ
04234  4264           ZEROIT  /IT WAS A CR, STORE THE
04235  0000           0       /TERMINATOR IN MEMORY.
04236  0074           COMI
04237  0254           254     /A COMMA SEPARATES
04240  0110           JPFZ    /ARRAY NUMBERS
04241  4256           NMBR
04242  0000           0
04243  0134           LXMC
04244  0106           JSUN
04245  4252           INCRLH
04246  0000           0
04247  0104           JPUN
04250  4226           DATA
04251  0000           0
04252  0060  INCRLH,  INCL
04253  0013           RTFZ
04254  0050           INCH
04255  0007           RTUN

04256  0106  NMBR,    JSUN
04257  5654           BCDBIN
04260  0000           0
04261  0104           JPUN
04262  4226           DATA
04263  0000           0
```

```
04264   0134  ZEROIT, LXMC     /SAVE PRESENT CONVERSUON
04265   0060          INCL
04266   0250          XORA     /SAVE A 0 AFTER THE
04267   0114          LXMA     /LAST DATA VALUE
04270   0106  CALIB,  JSUN     /PLOTTER ON !!!!!
04271   5343          LISTER   /CALIBRATE THE PLOTTER !
04272   0000          0
04273   0106          JSUN     /ENABLE THE PLOTTER
04274   5370          ENABLE
04275   0000          0
04276   0006  NOVAL,  LDAI     /STOP THE DISPLAY BUFFER
04277   0047          BUFF47
04300   0171          DS
04301   0173          IOP1
04302   0106          JSUN
04303   3120          TTYIN
04304   0000          0
04305   0303          LDAD
04306   0074          COMI
04307   0330          330
04310   0150          JPTZ     /X=MAXIMUM X DEFLECTION
04311   4345          MAXX
04312   0000          0
04313   0074          COMI
04314   0331          331
04315   0150          JPTZ     /Y=MAXIMUM Y DEFLECTION
04316   4355          MAXY
04317   0000          0
```

```
Ø432Ø  ØØ74          COMI
Ø4321  Ø317          317
Ø4322  Ø15Ø          JPTZ     /O=GO TO THE ORIGIN
Ø4323  4365          ORIGIN
Ø4324  ØØØØ          Ø
Ø4325  ØØ74          COMI
Ø4326  Ø3Ø7          3Ø7
Ø4327  Ø15Ø          JPTZ     /G=DRAW THE BOX
Ø433Ø  4373          BOX
Ø4331  ØØØØ          Ø
Ø4332  ØØ74          COMI
Ø4333  Ø323          323
Ø4334  Ø15Ø          JPTZ     /S=SKIP THE BOX PLOT
Ø4335  4621          FINISH
Ø4336  ØØØØ          Ø
Ø4337  ØØ74          COMI
Ø434Ø  Ø321          321
Ø4341  Ø11Ø          JPFZ     /Q=QUIT OR HALT
Ø4342  4276          NOVAL
Ø4343  ØØØØ          Ø
Ø4344  ØØØØ          HALT
Ø4345  ØØØ6  MAXX,   LDAI     /SET X=376,Y=ØØØ
Ø4346  Ø376          376
Ø4347  Ø137          XDAC
Ø435Ø  Ø25Ø          XORA
Ø4351  Ø135          YDAC
```

```
04352  0104              JPUN
04353  4276              NOVAL
04354  0000              0
04355  0006  MAXY,       LDAI      /SET X=000,Y=376
04356  0376              376
04357  0135              YDAC
04360  0250              XORA
04361  0137              XDAC
04362  0104              JPUN
04363  4276              NOVAL
04364  0000              0
04365  0250  ORIGIN,     XORA      /SET X=000,Y=000
04366  0137              XDAC
04367  0135              YDAC
04370  0104              JPUN
04371  4276              NOVAL
04372  0000              0
04373  0106  BOX,        JSUN      /G=DRAW THE BOX
04374  5667              CLEAN
04375  0000              0
04376  0137              XDAC      /PEN IS AT THE ORIGIN
04377  0135              YDAC
04400  0106              JSUN      /WAIT .65 SECONDS
04401  4502              WAIT1
04402  0000              0
04403  0106              JSUN      /PUT THE PEN DOWN
04404  4476              PNDWN
04405  0000              0
04406  0010  XLIN,       INCB      /THIS DRAWS THE BOTTOM
```

```
Ø44Ø7  Ø15Ø           JPTZ
Ø441Ø  442Ø           YLIN
Ø4411  ØØØØ           Ø
Ø4412  Ø1Ø6           JSUN
Ø4413  4462           OUTPUT
Ø4414  ØØØØ           Ø
Ø4415  Ø1Ø4           JPUN
Ø4416  44Ø6           XLIN
Ø4417  ØØØØ           Ø
Ø442Ø  ØØ16   YLIN,   LDBI      /THEN THE RIGHT SIDE
Ø4421  Ø377           377
Ø4422  ØØ2Ø           INCC
Ø4423  Ø15Ø           JPTZ
Ø4424  4434           NXLIN
Ø4425  ØØØØ           Ø
Ø4426  Ø1Ø6           JSUN
Ø4427  4462           OUTPUT
Ø443Ø  ØØØØ           Ø
Ø4431  Ø1Ø4           JPUN
Ø4432  442Ø           YLIN
Ø4433  ØØØØ           Ø
Ø4434  ØØ26   NXLIN,  LDCI      /THEN THE TOP
Ø4435  Ø377           377
Ø4436  ØØ11           DECB
Ø4437  Ø15Ø           JPTZ
Ø444Ø  445Ø           NYLIN
Ø4441  ØØØØ           Ø
```

```
04442  0106           JSUN
04443  4462           OUTPUT
04444  0000           0
04445  0104           JPUN
04446  4434           NXLIN
04447  0000           0
04450  0021  NYLIN,   DECC      /THEN THE LEFT SIDE
04451  0150           JPTZ
04452  4547           TICS
04453  0000           0
04454  0106           JSUN
04455  4462           OUTPUT
04456  0000           0
04457  0104           JPUN
04460  4450           NYLIN
04461  0000           0

04462  0115  OUTPUT,  SR1       /WAIT FOR THE R-C CLOCK
04463  0044           ANDI
04464  0001           NE555
04465  0110           JPFZ
04466  4462           OUTPUT
04467  0000           0
04470  0301           LDAB      /IT'S A 1 NOW (NE555)
04471  0137           XDAC
04472  0302           LDAC
04473  0135           YDAC
04474  0250           XORA
```

```
Ø4475  ØØØ7           RTUN

Ø4476  ØØØ6  PNDWN,   LDAI    /PUT THE PEN DOWN
Ø4477  ØØ44           PEN44
Ø45ØØ  Ø171           DS
Ø45Ø1  Ø173           IOP1
Ø45Ø2  Ø25Ø  WAIT1,   XORA    /WAIT .65 SECONDS
Ø45Ø3  ØØ46           LDEI
Ø45Ø4  ØØØØ           ØØØ
Ø45Ø5  ØØ36           LDDI
Ø45Ø6  ØØ4Ø           Ø4Ø
Ø45Ø7  ØØ4Ø  WAIT2,   INCE
Ø451Ø  Ø11Ø           JPFZ
Ø4511  45Ø7           WAIT2
Ø4512  ØØØØ           Ø
Ø4513  ØØ31           DECD
Ø4514  Ø11Ø           JPFZ
Ø4515  45Ø7           WAIT2
Ø4516  ØØØØ           Ø
Ø4517  ØØØ7           RTUN

Ø452Ø  ØØØ6  PNUP,    LDAI    /LIFT THE PEN UP
Ø4521  ØØ44           PEN44
Ø4522  Ø171           DS
Ø4523  Ø175           IOP2
Ø4524  ØØØ7           RTUN
```

```
               /INPUT A TELETYPE CHARACTER AND
               /CONVERT IT TO THE BINARY NUMBER.

04525  0106  INPUT,  JSUN
04526  5667          CLEAN
04527  0000          0
04530  0106  NOCR,   JSUN
04531  3120          TTYIN
04532  0000          0
04533  0074          COMI
04534  0260          260
04535  0043          RTTC
04536  0074          COMI
04537  0272          272
04540  0003          RTFC
04541  0106          JSUN
04542  5654          BCDBIN
04543  0000          0
04544  0104          JPUN
04545  4530          NOCR
04546  0000          0
```

```
04547 0106 TICS,   JSUN    /SET XDAC=YDAC=000
04550 4462         OUTPUT
04551 0000         0
04552 0106         JSUN    /LIFT THE PEN UP
04553 4520         PNUP
04554 0000         0
04555 0106         JSUN    /WAIT .65 SECONDS
04556 4502         WAIT1
04557 0000         0
04560 0250         XORA
04561 0320         LDCA    /C=YDAC=000
04562 0016         LDBI    /B=DISTANCE BETWEEN
04563 0063         063     /SUCCESSIVE TIC MARKS
04564 0106 NXTTIC, JSUN    /SET XDAC=063,YDAC=000
04565 4462         OUTPUT
04566 0000         0
04567 0106         JSUN    /WAIT .65 SECONDS
04570 4502         WAIT1
04571 0000         0
04572 0106         JSUN    /PUT THE PEN DOWN
04573 4476         PNDWN
04574 0000         0
04575 0026         LDCI
04576 0010         010
04577 0106         JSUN    /SET XDAC=063,YDAC=010
04600 4462         OUTPUT
04601 0000         0
```

```
04602  0026          LDCI
04603  0000          000
04604  0106          JSUN     /SET XDAC=063,YDAC=000
04605  4462          OUTPUT
04606  0000          0
04607  0106          JSUN     /LIFT THE PEN UP
04610  4520          PNUP
04611  0000          0
04612  0301          LDAB
04613  0004          ADDI
04614  0063          063
04615  0310          LDBA     /SET B=B+063
04616  0100          JPFC     /HAVE WE DRAWN FIVE
04617  4564          NXTTIC   /TIC MARKS YET ?
04620  0000          0
04621  0250  FINISH, XORA
04622  0320          LDCA
04623  0310          LDBA
04624  0106          JSUN     /LIFT THE PEN UP
04625  4520          PNUP
04626  0000          0
04627  0106          JSUN     /SET XDAC=000,YDAC=000
04630  4462          OUTPUT
04631  0000          0
04632  0106          JSUN     /PUNCH ON !
04633  5343          LISTER   /ARE YOU READY ?
04634  0000          0
04635  0106  REPEAT, JSUN     /PUNCH OUT 6.4" OF LEADER
```

```
Ø4636  3Ø34           LDTR
Ø4637  ØØØØ           Ø
Ø464Ø  ØØ56           LDHI
Ø4641  ØØ1Ø           Ø1Ø
Ø4642  ØØ66           LDLI
Ø4643  ØØ77           Ø77
Ø4644  Ø146           LXDM      /PUNCH THE TBS ON THE TAPE
Ø4645  Ø1Ø6           JSUN
Ø4646  3127           TTYOUT
Ø4647  ØØØØ           Ø
Ø465Ø  Ø3Ø7  ARROUT,  LDAM      /NOW PUNCH OUT ALL THE ARRAY
Ø4651  5676           PNT1      /NUMBERS ON THE PAPER TAPE
Ø4652  ØØØØ           Ø
Ø4653  ØØØØ           Ø
Ø4654  ØØØØ           Ø
Ø4655  ØØ74           COMI
Ø4656  ØØØØ           ØØØ       /FOUND THE TERMINATOR YET ?
Ø4657  Ø15Ø           JPTZ
Ø466Ø  4674           TERMIT
Ø4661  ØØØØ           Ø
Ø4662  Ø33Ø           LDDA      /NO, PUNCH OUT THE ARRAY #
Ø4663  Ø1Ø6           JSUN
Ø4664  3127           TTYOUT
Ø4665  ØØØØ           Ø
Ø4666  Ø1Ø6           JSUN      /AND GET ANOTHER ONE
Ø4667  4252           INCRLH
Ø467Ø  ØØØØ           Ø
```

```
Ø4671  Ø1Ø4           JPUN     /AND DO IT AGAIN
Ø4672  4654           ARROUT+4
Ø4673  ØØØØ           Ø
Ø4674  Ø33Ø  TERMIT,  LDDA     /WE FOUND THE TERMINATOR
Ø4675  Ø1Ø6           JSUN     /SO PUNCH IT OUT ALSO
Ø4676  3127           TTYOUT
Ø4677  ØØØØ           Ø
Ø47ØØ  Ø1Ø3  GOWAIT,  INP1     /WAIT FOR ANY TELETYPE
Ø47Ø1  ØØ32           RARC     /CHARACTER TO INITIATE
Ø47Ø2  Ø1ØØ           JPFC     /THE ACQUISITION OF DATA
Ø47Ø3  47ØØ           GOWAIT
Ø47Ø4  ØØØØ           Ø
Ø47Ø5  Ø1Ø4  TIMER,   JPUN
Ø47Ø6  5Ø26           INT1     /SIMULATE SERVICING AN INTERRUPT !
Ø47Ø7  ØØØØ           Ø
Ø471Ø  Ø1Ø3  NXTSPC,  INP1     /DOES THE USER WANT TO DO
Ø4711  ØØ32           RARC     /ANYTHING SPECIAL ?
Ø4712  Ø1ØØ           JPFC     /(WHERE ANY TELETYPE KEYS
Ø4713  471Ø           NXTSPC   /PRESSED ?)
Ø4714  ØØØØ           Ø        /NO, KEEPING CHECKING
Ø4715  Ø1Ø1           INPØ
Ø4716  ØØ74           COMI
Ø4717  Ø316           316      /N=GET ANOTHER SPECTRA
Ø472Ø  Ø11Ø           JPFZ     /IRRESPECTIVE OF THE RTC !
Ø4721  4734           QPLOT    /NOT AN N, IS IT A P ?
Ø4722  ØØØØ           Ø
Ø4723  Ø1Ø6           JSUN     /GET A SPECTRA
Ø4724  515Ø           RETCON
```

```
04725  0000          0
04726  0106          JSUN     /SCALE AND DISPLAY IT
04727  4021          SCALE
04730  0000          0
04731  0104          JPUN     /WAIT FOR ANOTHER
04732  4710          NXTSPC   /TELETYPE CHARACTER
04733  0000          0
04734  0074  QPLOT,  COMI
04735  0320          320      /P=PLOT THE COMPLETE SPECTRA
04736  0110          JPFZ     /NOT A P, IS IT AN S ?
04737  4747          NOAP
04740  0000          0
04741  0106          JSUN     /LINE PLOT THE
04742  5576          ALLPLT   /COMPLETE SPECTRA
04743  0000          0
04744  0104          JPUN
04745  4710          NXTSPC
04746  0000          0
04747  0074  NOAP,   COMI
04750  0323          323      /S=SAVE THE COMPLETE SPECTRA
04751  0110          JPFZ     /NOT AN S, IS IT AN I ?
04752  4777          NOSAVE
04753  0000          0
04754  0337          LDDM     /GET THE CURRENT HI POINTER
04755  4030          HIP
04756  0000          0
04757  0000          0
04760  0000          0
```

```
04761  0066           LDLI
04762  0000           000
04763  0056  NPSAVE,  LDHI
04764  0017           017     /GET A DATA VALUE
04765  0116           LXAM
04766  0353           LDHD    /SWITCH THE HI ADDRESSES
04767  0114           LXMA    /SAVE THE DATA VALUE
04770  0060           INCL    /SAVE ANOTHER DATA POINT ?
04771  0110           JPFZ    /YES
04772  4763           NPSAVE
04773  0000           0
04774  0104           JPUN    /DON'T INCREMENT H UNLESS THE I
04775  4710           NXTSPC  /KEY IS TYPED IN (FOR INCREMENT).
04776  0000           0
04777  0074  NOSAVE,  COMI
05000  0311           311     /I=INCREMENT HIP FOR SAVING
05001  0110           JPFZ    /THE COMPLETE SPECTRA.
05002  5016           NOINC   /THIS WAY WE CAN FILL MEMORY
05003  0000           0       /WITH THE BEST SPECTRA
05004  0317           LDBM
05005  4030           HIP
05006  0000           0
05007  0000           0
05010  0000           0       /GET "HIP"
05011  0010           INCB    /INCREMENT IT
05012  0124           LXMB    /AND SAVE IT AGAIN
05013  0104           JPUN
```

```
05014  4710           NXTSPC
05015  0000           0
05016  0074  NOINC,   COMI
05017  0321           321      /Q=QUIT.
05020  0150           JPTZ
05021  4043           SRTC     /STOP THE REAL TIME CLOCK
05022  0000           0        /AND GO BACK TO THE EXECUTIVE
05023  0104           JPUN     /NOT A VALID COMMAND (KEY)
05024  4710           NXTSPC   /SO IGNORE IT.
05025  0000           0
```

```
05026 0006 INT1,  LDAI
05027 0040        RTC40   /START THE REAL TIME
05030 0171        DS      /CLOCK IMMEDIATELY
05031 0177        IOP3
05032 0175        IOP2
05033 0317        LDBM    /NOW GET "XPOS" AND
05034 5575        XPOS    /INCREMENT IT
05035 0000        0       /"XPOS" IS THE CURRENT X
05036 0000        0       /COORDINATE FOR THE MULTI-
05037 0000        0       /TRACE PLOT.
05040 0010        INCB    /WE DO THIS EVERYTIME AN
05041 0124        LXMB    /INTERRUPT OCCURS !
05042 0106 SERRTC, JSUN   /THE RETURN IS PLACED HERE !
05043 5150        RETCON  /GET THE DATA FROM THE ARRAY
05044 0000        0
05045 0106        JSUN    /SCALE THE DATA
05046 3350        DATCRT  /AND BASELINE CORRECT IT.
05047 0000        0
05050 0106        JSUN    /AND COMPRESS IT FOR THE
05051 5406        CMPRS   /DESIRED ARRAY NUMBERS
05052 0000        0
05053 0307        LDAM    /SEE IF WE HAVE ENOUGH TIME
05054 4077        TBSM    /TO PLOT OUT THE DATA OR JUST
05055 0000        0       /PUNCH IT OUT.
05056 0000        0
05057 0000        0
```

```
Ø5Ø6Ø  ØØ74          COMI
Ø5Ø61  ØØ12          Ø12      /IS IT LESS THAN 1Ø SECS ?
Ø5Ø62  Ø14Ø          JPTC     /YES, NO TIME TO PLOT IT
Ø5Ø63  5Ø7Ø          NOPLOT
Ø5Ø64  ØØØØ          Ø
Ø5Ø65  Ø1Ø6          JSUN     /WE HAVE ENOUGH TIME TO
Ø5Ø66  55Ø4          PNTPLT   /PLOT THE DATA OUT.
Ø5Ø67  ØØØØ          Ø
Ø5Ø7Ø  Ø1Ø6  NOPLOT, JSUN
Ø5Ø71  5113          DISPLA   /GET THE DISPLAY CONTROLLER GOING
Ø5Ø72  ØØØØ          Ø
Ø5Ø73  Ø1Ø6          JSUN
Ø5Ø74  2766          PUNCH    /AND PUNCH OUT THE COMPRESSED DATA.
Ø5Ø75  ØØØØ          Ø
Ø5Ø76  Ø347  NXTPCH, LDEM     /GET THE NUMBER OF TIMES
Ø5Ø77  5675          NMSPC    /THE REAL TIME CLOCK HAS
Ø51ØØ  ØØØØ          Ø        /BEEN SERVICED.
Ø51Ø1  ØØØØ          Ø
Ø51Ø2  ØØØØ          Ø
Ø51Ø3  ØØ41          DECE     /DECREMENT AND SAVE IT.
Ø51Ø4  Ø154          LXME
Ø51Ø5  Ø11Ø          JPFZ     /256 SERVICES YET ?
Ø51Ø6  471Ø          NXTSPC   /NO, WAIT FOR THE TELETYPE
Ø51Ø7  ØØØØ          Ø        /OR THE REAL TIME CLOCK
Ø511Ø  Ø1Ø4          JPUN     /YES, STOP THE REAL TIME
Ø5111  4Ø43          SRTC     /CLOCK AND GO BACK TO THE
Ø5112  ØØØØ          Ø        /EXECUTIVE
Ø5113  Ø1Ø6  DISPLA, JSUN     /DISPLAY THE DATA SO
Ø5114  5375          DISABL   /DISABLE THE PLOTTER
```

```
05115  0000          0
05116  0056          LDHI      /H=017, L=000 - 377 FOR
05117  0017          017       /THE MOST CURRENT SPECTRA
05120  0066          LDLI
05121  0000          000
05122  0006  MORDSP, LDAI
05123  0047          BUFF47
05124  0171          DS
05125  0173          IOP1      /LOCK OUT THE DISPLAY
05126  0250          XORA      /BUFFER'S CLOCK.
05127  0137          XDAC      /SET ADDRESSS REG. TO 000
05130  0116  NXTSCP, LXAM      /GET A DATA VALUE
05131  0135          YDAC      /WRITE IT IN THE BUFFER MEMORY
05132  0175          IOP2      /INCREMENT THE ADDRESS REGISTER
05133  0060          INCL      /ANY DATA LEFT ?
05134  0110          JPFZ      /YES, GET ANOTHER DATA VALUE
05135  5130          NXTSCP
05136  0000          0
05137  0177          IOP3      /NO, START THE BUFFER UP
05140  0007          RTUN      /THE BUFFER IS NOW RUNNING

05141  0106  GETNXT, JSUN      /GET A SPECTRA
05142  5150          RETCON
05143  0000          0
05144  0106          JSUN      /NOW DISPLAY IT
05145  5113          DISPLA
05146  0000          0
05147  0007          RTUN
```

```
                  /THIS IS WHERE WE SERVICE THE PHOTODIODE
                  /LINEAR ARRAY.

Ø515Ø  ØØ46  RETCON, LDEI
Ø5151  ØØØ2          ØØ2     /SET 512 MEMORY LOCATIONS
Ø5152  ØØ56          LDHI    /TO ØØØ.
Ø5153  ØØ17          Ø17
Ø5154  ØØ66          LDLI
Ø5155  ØØØØ          ØØØ
Ø5156  ØØ76          LDMI
Ø5157  ØØØØ          ØØØ
Ø516Ø  ØØ6Ø          INCL
Ø5161  Ø11Ø          JPFZ
Ø5162  5156          RETCON+6
Ø5163  ØØØØ          Ø
Ø5164  ØØ5Ø          INCH
Ø5165  ØØ41          DECE
Ø5166  Ø11Ø          JPFZ
Ø5167  5156          RETCON+6
Ø517Ø  ØØØØ          Ø
Ø5171  ØØ26          LDCI
Ø5172  ØØ2Ø          Ø2Ø     /# OF SPECTRA.
Ø5173  ØØØ6  RET1,   LDAI
Ø5174  ØØ41          BIO41
Ø5175  Ø171          DS
Ø5176  Ø173          IOP1    /CHARGE THE ARRAY UP
```

```
05177  0036            LDDI
05200  0007  ITIME,    007
05201  0046            LDEI
05202  0012            012       /WAIT FOR THE USER SPECIFIED
05203  0041  WAIT3,    DECE      /NUMBER OF ONE MILLISECOND
05204  0110            JPFZ      /TIME PERIODS.
05205  5203            WAIT3
05206  0000            0
05207  0031            DECD      /THE DELAY LOOP IS REALLY
05210  0110            JPFZ      /960 MICROSECONDS.
05211  5201            ITIME+1
05212  0000            0
05213  0173            IOP1      /SWEEP OUT THE RETICON
05214  0036            LDDI      /THIS IS WHERE WE START STORING THE
05215  0017            017
05216  0046            LDEI      /THE DOUBLE PRECISION RESULTS.
05217  0000            000
05220  0066            LDLI
05221  0000            000
05222  0316            LDBL
05223  0361  NXTPT,    LDLB
05224  0056            LDHI
05225  0004            004       /H&L TO THE D.C.
05226  0115            SR1
05227  0044            ANDI      /DATA READY FLAG.
05230  0002            002
05231  0150            JPTZ
05232  5226            NXTPT+3
```

```
Ø5233  ØØØØ          Ø
Ø5234  Ø113          READ     /INPUT THE BTR'S DATA
Ø5235  Ø175          IOP2     /PULSE THE WORD COMMAND LINE
Ø5236  Ø227          SUBM     /SUBTRACT THE D.C.
Ø5237  ØØ6Ø          INCL
Ø524Ø  Ø316          LDBL
Ø5241  Ø353          LDHD
Ø5242  Ø364          LDLE
Ø5243  Ø2Ø7          ADDM     /ADD THE PREVIOUS VALUE
Ø5244  Ø114          LXMA     /STORE THE DATA IN MEMORY
Ø5245  Ø1Ø6          JSUN
Ø5246  4252          INCRLH
Ø5247  ØØØØ          Ø
Ø525Ø  Ø116          LXAM
Ø5251  ØØ14          ACI
Ø5252  ØØØØ          ØØØ      /"SAVE" THE RESULTS OF ANY CARRY.
Ø5253  Ø114          LXMA
Ø5254  Ø1Ø6          JSUN
Ø5255  4252          INCRLH
Ø5256  ØØØØ          Ø
Ø5257  Ø335          LDDH
Ø526Ø  Ø346          LDEL
Ø5261  Ø3Ø1          LDAB
Ø5262  ØØ74          COMI
Ø5263  Ø373          373
Ø5264  Ø11Ø          JPFZ
Ø5265  5223          NXTPT
Ø5266  ØØØØ          Ø
```

```
05267  0021           DECC    /16 AVERAGES YET ?
05270  0110           JPFZ
05271  5173           RET1
05272  0000           0
05273  0026           LDCI    /YES, GET THE EIGHT VALID
05274  0000           000     /DATA BITS
05275  0036           LDDI
05276  0017           017
05277  0046           LDEI
05300  0000           000
05301  0353  C2BIT,   LDHD
05302  0364           LDLE
05303  0116           LXAM    /GET THE LO PORTION.
05304  0044           ANDI
05305  0370           370
05306  0310           LDBA    /SAVE THE LO
05307  0106           JSUN
05310  4252           INCRLH
05311  0000           0
05312  0116           LXAM
05313  0106           JSUN
05314  4252           INCRLH
05315  0000           0
05316  0044           ANDI
05317  0003           003     /GET THE HI PORTION.
05320  0201           ADDB
05321  0012           RART
```

```
05322  0012          RART     /DIVIDE THE NUMBER BY 4
05323  0310          LDBA
05324  0335          LDDH
05325  0346          LDEL
05326  0056          LDHI
05327  0017          017
05330  0362          LDLC
05331  0124          LXMB     /SAVE THE RESULT
05332  0060          INCL
05333  0326          LDCL
05334  0306          LDAL
05335  0074          COMI
05336  0373          373
05337  0110          JPFZ
05340  5301          C2BIT
05341  0000          0
05342  0007          RTUN

               /LISTER IS USED TO PRINT OUT THE MESSAGES
               /STORED ON PAPER TAPE.  AT THE END OF EACH
               /MESSAGE A 377 (RUBOUT) IS STORED AS A
               /MESSAGE TERMINATOR.

05343  0250  LISTER, XORA
05344  0310          LDBA
05345  0006          LDAI     /TURN THE READER ON
05346  0001          001
```

```
05347  0123           OUT1
05350  0010  RDRWAT,  INCB
05351  0110           JPFZ
05352  5350           RDRWAT
05353  0000           0
05354  0250           XORA
05355  0123           OUT1     /TURN THE READER OFF.
05356  0106           JSUN
05357  3120           TTYIN
05360  0000           0
05361  0303           LDAD
05362  0074           COMI
05363  0377           377      /FIND A RUBOUT YET ?
05364  0053           RTTZ     /YES, EXIT FROM THIS ROUTINE
05365  0104           JPUN     /NOT A 377, GET
05366  5343           LISTER   /ANOTHER CHARACTER
05367  0000           0

05370  0006  ENABLE,  LDAI     /ENABLE THE PLOTTER BY
05371  0043           PLTENB   /TURN THE DPDT RELAY ON.
05372  0171           DS
05373  0177           IOP3
05374  0007           RTUN
05375  0006  DISABL,  LDAI
05376  0047           BUFF47
05377  0171           DS
05400  0173           IOP1     /LOCK OUT THE DISPLAY BUFFER
05401  0006           LDAI
```

```
05402  0043          PLTENB
05403  0171          DS
05404  0175          IOP2     /AND DISABLE THE PLOTTER.
05405  0007          RTUN

05406  0056  CMPRS,  LDHI     /010 035 (4035) IS A
05407  0010          010      /TEMPOARY DATA POINTER
05410  0066          LDLI
05411  0035          035
05412  0076          LDMI     /THE LO ADDRESS OF THE
05413  0100          100      /COMPRESSED DATA POINTER
05414  0307          LDAM     /H&L NOW POINT TO THE LIST
05415  5676          PNT1     /OF USER SELECTED ARRAY NUMBERS
05416  0000          0
05417  0000          0
05420  0116  NXTAB,  LXAM     /GET AN ARRAY NUMBER
05421  0074          COMI
05422  0000          000      /A 000 IS THE ARRAY
05423  0150          JPTZ     /LIST TERMINATOR
05424  5471          ZERO
05425  0000          0
05426  0060          INCL     /INCREMENT THE ARRAY POINTER
05427  0346          LDEL     /AND SAVE IT IN E.
05430  0056          LDHI
05431  0017          017      /THIS IS WHERE THE SECTRA IS STORED
05432  0360          LDLA     /USE THE ARRAY NUMBER AS
```

```
Ø5433  Ø136        LXCM    /THE LO ADDRESS. GET THE DATA.
Ø5434  ØØ56        LDHI
Ø5435  ØØ1Ø        Ø1Ø
Ø5436  ØØ66        LDLI    /GET THE COMPRESSED DATA
Ø5437  ØØ35        Ø35     /BUFFER ADDRESS POINTER
Ø544Ø  Ø116        LXAM    /GET THE POINTER
Ø5441  Ø36Ø        LDLA
Ø5442  Ø3Ø2        LDAC    /SET A=DATA VALUE
Ø5443  ØØ54        XORI    /COMPLEMENT IT.
Ø5444  Ø377        377
Ø5445  ØØ12        RART
Ø5446  ØØ44        ANDI
Ø5447  Ø177        177     /DIVIDE THE DATA BY TWO
Ø545Ø  Ø114        LXMA    /AND SAVE IT IN MEMORY.
Ø5451  ØØ6Ø        INCL
Ø5452  Ø3Ø6        LDAL
Ø5453  ØØ66        LDLI    /INCREMENT AND SAVE THE
Ø5454  ØØ35        Ø35     /COMPRESSED DATA POINTER
Ø5455  ØØ56        LDHI    /IN Ø1Ø Ø35 (4Ø35).
Ø5456  ØØ1Ø        Ø1Ø
Ø5457  Ø114        LXMA    /SAVE THE POINTER
Ø546Ø  Ø3Ø7        LDAM
Ø5461  5676        PNT1    /SET H&L TO POINT TO THE
Ø5462  ØØØØ        Ø       /ARRAY NUMBER TABLE AGAIN.
Ø5463  ØØØØ        Ø
Ø5464  ØØØØ        Ø
Ø5465  Ø364        LDLE
Ø5466  Ø1Ø4        JPUN
Ø5467  542Ø        NXTAB   /AND COMPRESS THE NEXT POINT
```

```
05470  0000           0
05471  0056  ZERO,    LDHI       /SAVE A 377 TERMINATOR AFTER
05472  0010           010        /THE LAST COMPRESSED DATA
05473  0066           LDLI       /VALUE STORED IN MEMORY.
05474  0035           035
05475  0116           LXAM
05476  0360           LDLA
05477  0056           LDHI
05500  0010           010
05501  0076           LDMI
05502  0377           377
05503  0007           RTUN
```

```
05504  0006  PNTPLT, LDAI      /LOCK OUT THE DISPLAY BUFFER
05505  0047          BUFF47
05506  0171          DS
05507  0173          IOP1
05510  0106          JSUN      /AND ENABLE THE PLOTTER
05511  5370          ENABLE
05512  0000          0
05513  0250          XORA
05514  0135          YDAC
05515  0307          LDAM      /GET THE CURRENT X AXIS
05516  5575          XPOS      /POSITION
05517  0000          0
05520  0000          0
05521  0000          0
05522  0137          XDAC      /AND MOVE THE PEN THERE.
05523  0106          JSUN
05524  4502          WAIT1     /WAIT FOR PEN TO SETTLE
05525  0000          0
05526  0056          LDHI      /SET H&L TO THE
05527  0010          010       /COMPRESSED DATA FILE.
05530  0066          LDLI
05531  0100          100
05532  0046          LDEI      /THIS IS THE AMOUNT OF OFFSET
05533  0030          030       /BETWEEN ADJACENT TRACES.
05534  0036          LDDI
05535  0000          000
05536  0303  NXTPOS, LDAD
```

```
05537  0204   ADDE
05540  0330   LDDA     /D=CURRENT Y BIAS FACTOR
05541  0116   LXAM     /GET A DATA VALUE
05542  0074   COMI     /HAVE WE FOUND THE
05543  0377   377      /END OF THE TABLE ?
05544  0150   JPTZ     /YES, DISABLE THE PLOTTER
05545  5375   DISABL   /AND ENABLE THE DISPLAY BUFFER.
05546  0000   0
05547  0060   INCL
05550  0203   ADDD     /SET A=DATA+BIAS FACTOR
05551  0135   YDAC     /AND PLOT THE POINT.
05552  0313   LDBD
05553  0324   LDCE     /D&E ARE USED IN PNUP & PNDWN
05554  0106   JSUN     /WAIT .65 SECONDS FOR THE
05555  4502   WAIT1    /PLOTTER TO SETTLE.
05556  0000   0
05557  0106   JSUN     /PUT THE PEN DOWN
05560  4476   PNDWN
05561  0000   0
05562  0106   JSUN     /LIFT THE PEN UP
05563  4520   PNUP
05564  0000   0
05565  0106   JSUN     /WAIT .65 SECONDS AGAIN
05566  4502   WAIT1
05567  0000   0
05570  0331   LDDB
05571  0342   LDEC     /RESTORE THE BIAS FACTORS
05572  0104   JPUN
```

```
05573  5536          NXTPOS
05574  0000          0
05575  0000  XPOS,   000

             /P=PLOT OUR MOST RECENT SPECTRA
             /IN THE FORM OF A LINE PLOT.

05576  0006  ALLPLT, LDAI
05577  0047          BUFF47
05600  0171          DS
05601  0173          IOP1    /DISABLE THE BUFFER
05602  0106          JSUN
05603  5370          ENABLE  /ENABLE THE PLOTTER
05604  0000          0
05605  0006          LDAI    /THIS SUBSTITUTES A "RETURN" AFTER
05606  0007          007     /INCREMENTING "XPOS", SO THAT THE
05607  0370          LDMA    /PLOTTER STAYS SYNCHRONIZED IN
05610  5042          SERRTC  /THE MULTI-TRACE MODE WITH REAL
05611  0000          0       /TIME SPECTRA.
05612  0000          0
05613  0000          0
05614  0056          LDHI    /H&L POINT TO THE
05615  0017          017     /SPECTRAL DATA VALUES.
05616  0066          LDLI
05617  0001          001
05620  0116  AGAIN,  LXAM    /DATA TO THE YDAC
```

```
Ø5621  Ø135            YDAC
Ø5622  Ø3Ø6            LDAL     /THE LO ADDRESS TO
Ø5623  Ø137            XDAC     /THE XDAC
Ø5624  ØØØ6            LDAI
Ø5625  ØØ44            PEN44
Ø5626  Ø171            DS
Ø5627  Ø173            IOP1     /PUT THE PEN DOWN
Ø563Ø  Ø115   PLTWAT,  SR1      /WAIT FOR THE R-C CLOCK
Ø5631  ØØ44            ANDI
Ø5632  ØØØ1            NE555
Ø5633  Ø11Ø            JPFZ
Ø5634  563Ø            PLTWAT
Ø5635  ØØØØ            Ø
Ø5636  ØØ6Ø            INCL     /ANY DATA LEFT ?
Ø5637  Ø11Ø            JPFZ     /YES, GET ANOTHER
Ø564Ø  562Ø            AGAIN    /DATA VALUE FROM MEMORY.
Ø5641  ØØØØ            Ø
Ø5642  ØØØ6            LDAI     /AFTER WE HAVE PLOTTED THE
Ø5643  Ø1Ø6            1Ø6      /DATA, WE REPLACE THE "RETURN"
Ø5644  Ø37Ø            LDMA     /WITH THE "JUMP" THAT WAS THERE
Ø5645  5Ø42            SERRTC   /BEFORE.  THE REAL TIME CLOCK
Ø5646  ØØØØ            Ø        /WILL NOW FUNCTION IN THE
Ø5647  ØØØØ            Ø        /NORMAL MANNER.
Ø565Ø  ØØØØ            Ø
Ø5651  Ø1Ø4            JPUN     /LIFT THE PEN UP
Ø5652  452Ø            PNUP
Ø5653  ØØØØ            Ø

              /THIS IS THE BCD TO BINARY
```

```
                  /CONVERSION SUBROUTINE.

05654  0024  BCDBIN, SUBI
05655  0260          260
05656  0310          LDBA
05657  0302          LDAC
05660  0022          RALC
05661  0022          RALC
05662  0202          ADDC
05663  0022          RALC
05664  0201          ADDB
05665  0320          LDCA
05666  0007          RTUN
05667  0250  CLEAN,  XORA
05670  0310          LDBA
05671  0320          LDCA
05672  0330          LDDA
05673  0340          LDEA
05674  0007          RTUN

05675  0000  NMSPC,  000      /THE NUMBER OF SPECTRA
05676  0000  PNT1,   0        /THE ARRAY NUMBERS
05677  0000          0        /ARE STORED HERE.
05700  0000          0
05701  0000          0
05702  0000          0
05703  0000          0
```

```
Ø57Ø4  ØØØØ           Ø
Ø57Ø5  ØØØØ           Ø
Ø57Ø6  ØØØØ  T2,      Ø         /A TERMINATOR

             /ENTER DDIV WITH B&C EQUAL TO THE DIVIDEND
             /AND D&E EQUAL TO THE DIVISOR.  EXIT WITH
             /THE RESULT IN B (MSB) AND C (LSB).

Ø57Ø7  Ø372  DDIV,    LDMC
Ø571Ø  4Ø4Ø           TEMPD
Ø5711  ØØØØ           Ø
Ø5712  ØØØØ           Ø
Ø5713  ØØØØ           Ø
Ø5714  ØØ6Ø           INCL
Ø5715  Ø124           LXMB
Ø5716  ØØ6Ø           INCL
Ø5717  ØØ76           LDMI
Ø572Ø  ØØ21           Ø21
Ø5721  ØØ16           LDBI
Ø5722  ØØØØ           ØØØ
Ø5723  Ø321           LDCB
Ø5724  Ø3Ø4  NXTBIT,  LDAE
Ø5725  ØØ22           RALC
Ø5726  Ø34Ø           LDEA
Ø5727  Ø3Ø3           LDAD
Ø573Ø  ØØ22           RALC
Ø5731  Ø146           LXDM
Ø5732  ØØ31           DECD
```

```
05733  0144     LXMD
05734  0330     LDDA
05735  0053     RTTZ
05736  0302     LDAC
05737  0022     RALC
05740  0320     LDCA
05741  0301     LDAB
05742  0022     RALC
05743  0310     LDBA
05744  0307     LDAM
05745  4040     TEMPD
05746  0000     0
05747  0000     0
05750  0000     0
05751  0302     LDAC
05752  0227     SUBM
05753  0320     LDCA
05754  0060     INCL
05755  0301     LDAB
05756  0237     SBCM
05757  0310     LDBA
05760  0100     JPFC
05761  5773     NC
05762  0000     0
05763  0061     DECL
05764  0302     LDAC
05765  0207     ADDM
```

```
Ø5766  Ø32Ø          LDCA
Ø5767  ØØ6Ø          INCL
Ø577Ø  Ø3Ø1          LDAB
Ø5771  Ø217          ADCM
Ø5772  Ø31Ø          LDBA
Ø5773  ØØ56  NC,     LDHI     /WE JUST WANT TO SET UP H&L
Ø5774  ØØ1Ø          Ø1Ø
Ø5775  ØØ66          LDLI
Ø5776  ØØ42          Ø42
Ø5777  Ø23Ø          SBCA
Ø6ØØØ  ØØ34          SBCI
Ø6ØØ1  Ø2ØØ          2ØØ
Ø6ØØ2  Ø1Ø4          JPUN
Ø6ØØ3  5724          NXTBIT
Ø6ØØ4  ØØØØ          Ø

             /ENTER DMUL WITH B&C EQUAL TO THE MULTIPLICAND
             /AND D&E EQUAL TO THE MULTIPLIER.       EXIT
             /WITH THE RESULT IN B (MSB) AND C (LSB).
Ø6ØØ5  Ø372  DMUL,   LDMC
Ø6ØØ6  4Ø4Ø          TEMPD
Ø6ØØ7  ØØØØ          Ø
Ø6Ø1Ø  ØØØØ          Ø
Ø6Ø11  ØØØØ          Ø
Ø6Ø12  ØØ6Ø          INCL
Ø6Ø13  Ø124          LXMB
Ø6Ø14  ØØ6Ø          INCL
Ø6Ø15  ØØ76          LDMI
```

```
Ø6Ø16  ØØ21          Ø21
Ø6Ø17  ØØ16          LDBI
Ø6Ø2Ø  ØØØØ          ØØØ
Ø6Ø21  Ø321          LDCB
Ø6Ø22  Ø3Ø3  NXBIT,  LDAD
Ø6Ø23  ØØ32          RARC
Ø6Ø24  Ø33Ø          LDDA
Ø6Ø25  Ø3Ø4          LDAE
Ø6Ø26  ØØ32          RARC
Ø6Ø27  Ø156          LXEM
Ø6Ø3Ø  ØØ41          DECE
Ø6Ø31  Ø154          LXME
Ø6Ø32  Ø34Ø          LDEA
Ø6Ø33  ØØ53          RTTZ
Ø6Ø34  Ø1ØØ          JPFC
Ø6Ø35  6Ø6Ø          NC1
Ø6Ø36  ØØØØ          Ø
Ø6Ø37  Ø3Ø7          LDAM
Ø6Ø4Ø  4Ø4Ø          TEMPD
Ø6Ø41  ØØØØ          Ø
Ø6Ø42  ØØØØ          Ø
Ø6Ø43  ØØØØ          Ø
Ø6Ø44  Ø3Ø2          LDAC
Ø6Ø45  Ø2Ø7          ADDM
Ø6Ø46  Ø32Ø          LDCA
Ø6Ø47  ØØ6Ø          INCL
Ø6Ø5Ø  Ø3Ø1          LDAB
```

```
06051  0217           ADCM
06052  0310           LDBA
06053  0307           LDAM
06054  4042           TEMPD+2
06055  0000           0
06056  0000           0
06057  0000           0
06060  0301  NC1,     LDAB
06061  0032           RARC
06062  0310           LDBA
06063  0302           LDAC
06064  0032           RARC
06065  0320           LDCA
06066  0104           JPUN
06067  6022           NXBIT
06070  0000           0

06071  0106  CURSE,   JSUN     /GET A SPECTRA
06072  5141           GETNXT
06073  0000           0
06074  0106           JSUN     /AND SCALE IT.
06075  4021           SCALE
06076  0000           0
06077  0307           LDAM     /H&L POINT TO THE
06100  5676           PNT1     /ARRAY NUMBER TABLE.
06101  0000           0
06102  0000           0
06103  0000           0
```

```
06104  0006  NXTSC,  LDAI
06105  0047          BUFF47
06106  0171          DS
06107  0177          IOP3     /START THE DISPLAY BUFFER
06110  0026          LDCI
06111  0000          000
06112  0312          LDBC     /SET B=C=000
06113  0106  INTNXT, JSUN     /INTENSIFY ONE POINT
06114  6127          W1
06115  0000          0
06116  0010          INCB     /THE POINT INTENSIFIED HAS A
06117  0103          INP1     /LO ADDRESS EQUAL TO B.
06120  0032          RARC     /ANY TELETYPE KEY PRESSED ?
06121  0100          JPFC     /NO, INTENSIFY THE NEXT POINT.
06122  6113          INTNXT
06123  0000          0
06124  0104          JPUN     /YES, INTERPRETE THE COMMAND.
06125  6152          WAVEL
06126  0000          0

                     /THIS IS THE POINT INTENSIFICATION SUBROUTINE

06127  0020  W1,     INCC     /WAIT 20 MILLISECONDS.
06130  0110          JPFZ
06131  6127          W1
06132  0000          0
```

```
Ø6133  Ø173  NXTCP,  IOP1    /STOP THE BUFFER
Ø6134  Ø3Ø1          LDAB
Ø6135  Ø137          XDAC    /INTENSIFY THE POINT
Ø6136  ØØ2Ø  W2,     INCC    /WAIT ANOTHER 2Ø MILLISECONDS.
Ø6137  Ø11Ø          JPFZ
Ø614Ø  6136          W2
Ø6141  ØØØØ          Ø
Ø6142  Ø177          IOP3    /START THE BUFFER UP AGAIN
Ø6143  Ø115  CLKWAT, SR1     /WAIT FOR THE R-C CLOCK.
Ø6144  ØØ44          ANDI
Ø6145  ØØØ1          NE555   /THE R-C CLOCK DETERMINES HOW
Ø6146  Ø11Ø          JPFZ    /FAST THE CURSOR MOVES ACROSS
Ø6147  6143          CLKWAT  /THE CRT FACE.
Ø615Ø  ØØØØ          Ø
Ø6151  ØØØ7          RTUN
```

```
06152  0101  WAVEL,  INP0     /GET THE TELETYPE CHARACTER
06153  0074          COMI
06154  0302          302      /B=BACKUP 1 ARRAY #
06155  0110          JPFZ
06156  6174          FOR
06157  0000          0
06160  0011          DECB     /DECREMENT THE ARRAY NUMBER
06161  0106  KYWAT1, JSUN     /AND INTENSIFY THE POINT.
06162  6127          W1
06163  0000          0
06164  0103          INP1     /WAIT FOR A TELETYPE
06165  0032          RARC     /CHARACTER.
06166  0100          JPFC
06167  6161          KYWAT1
06170  0000          0
06171  0104          JPUN     /WHAT KEY WAS IT ?
06172  6152          WAVEL
06173  0000          0
06174  0074  FOR,    COMI
06175  0306          306      /F=FOWARD 1 ARRAY #
06176  0110          JPFZ
06177  6205          SAVE
06200  0000          0
06201  0010          INCB     /INCREMENT THE ARRAY NUMBER.
06202  0104          JPUN
06203  6161          KYWAT1
06204  0000          0
```

```
06205  0074  SAVE,   COMI     /S=SAVE THE ARRAY NUMBER
06206  0323          323      /AND OUTPUT IT TO THE TELETYPE.
06207  0110          JPFZ
06210  6233          CONTIN
06211  0000          0
06212  0124          LXMB     /H AND L WERE ALREADY SET UP
06213  0250          XORA
06214  0340          LDEA
06215  0330          LDDA
06216  0301          LDAB
06217  0106          JSUN     /TYPE OUT THE DECIMAL
06220  2733          BINBCD   /ARRAY NUMBER.
06221  0000          0
06222  0036          LDDI     /THEN TYPE OUT A COMMA.
06223  0254          254
06224  0106          JSUN
06225  3127          TTYOUT
06226  0000          0
06227  0060          INCL     /INCREMENT THE STORAGE POINTER.
06230  0104          JPUN     /WAIT FOR ANOTHER
06231  6161          KYWAT1   /TELETYPE CHARACTER.
06232  0000          0
06233  0074  CONTIN, COMI
06234  0303          303      /C=CONTINUE THE CURSOR'S
06235  0150          JPTZ     /MOVEMENT ACROSS THE CRT FACE.
06236  6113          INTNXT
06237  0000          0
06240  0074          COMI
```

```
Ø6241  Ø316             316     /G=GET ANOTHER SPECTRA
Ø6242  Ø11Ø             JPFZ
Ø6243  6256             NSCYET
Ø6244  ØØØØ             Ø
Ø6245  Ø1Ø6             JSUN
Ø6246  5141             GETNXT  /GET A SPECTRA
Ø6247  ØØØØ             Ø
Ø625Ø  Ø1Ø6             JSUN
Ø6251  335Ø             DATCRT  /AND SCALE AND DISPLAY IT.
Ø6252  ØØØØ             Ø
Ø6253  Ø1Ø4             JPUN
Ø6254  61Ø4             NXTSC
Ø6255  ØØØØ             Ø
Ø6256  ØØ74     NSCYET, COMI
Ø6257  Ø33Ø             33Ø
Ø626Ø  ØØ53             RTTZ
Ø6261  ØØ74             COMI
Ø6262  Ø324             324     /T=OUTPUT TRANSMITTANCE
Ø6263  Ø11Ø             JPFZ
Ø6264  637Ø             NOMORE
Ø6265  ØØØØ             Ø
Ø6266  ØØ36             LDDI    /TYPE "A="
Ø6267  Ø3Ø1             3Ø1
Ø627Ø  Ø1Ø6             JSUN    /A STANDS FOR ARRAY NUMBER
Ø6271  3127             TTYOUT  /NOT ABSORBANCE.
Ø6272  ØØØØ             Ø
Ø6273  ØØ36             LDDI
Ø6274  Ø275             275
```

```
Ø6275  Ø1Ø6       JSUN
Ø6276  3127       TTYOUT
Ø6277  ØØØØ       Ø
Ø63ØØ  Ø25Ø       XORA
Ø63Ø1  Ø33Ø       LDDA
Ø63Ø2  Ø34Ø       LDEA
Ø63Ø3  Ø3Ø1       LDAB
Ø63Ø4  Ø1Ø6       JSUN     /TYPE OUT THE DECIMAL
Ø63Ø5  2733       BINBCD   /ARRAY NUMBER.
Ø63Ø6  ØØØØ       Ø
Ø63Ø7  ØØ36       LDDI     /TYPE OUT ",T="
Ø631Ø  Ø254       254
Ø6311  Ø1Ø6       JSUN
Ø6312  3127       TTYOUT
Ø6313  ØØØØ       Ø
Ø6314  ØØ36       LDDI
Ø6315  Ø324       324
Ø6316  Ø1Ø6       JSUN
Ø6317  3127       TTYOUT
Ø632Ø  ØØØØ       Ø
Ø6321  ØØ36       LDDI
Ø6322  Ø275       275
Ø6323  Ø1Ø6       JSUN
Ø6324  3127       TTYOUT
Ø6325  ØØØØ       Ø
Ø6326  Ø3Ø5       LDAH
Ø6327  Ø316       LDBL     /SAVE THE STORAGE POINTERS
```

```
06330  0370        LDMA
06331  4040        TEMPD
06332  0000        0
06333  0000        0
06334  0000        0
06335  0060        INCL
06336  0124        LXMB
06337  0056        LDHI      /GET THE DATA VALUE
06340  0017        017       /REPRESENTED BY THE CURSOR'S
06341  0361        LDLB      /CURRENT POSITION.
06342  0250        XORA
06343  0330        LDDA
06344  0340        LDEA
06345  0116        LXAM
06346  0106        JSUN      /TYPE OUT THE TRANSMITTANCE
06347  2733        BINBCD    /FOR THAT PARTICULAR ARRAY
06350  0000        0         /NUMBER.
06351  0106        JSUN
06352  3234        CRLF
06353  0000        0
06354  0307        LDAM      /GET THE STORAGE POINTERS BACK
06355  4040        TEMPD
06356  0000        0
06357  0000        0
06360  0000        0
06361  0060        INCL
06362  0126        LXBM
```

```
Ø6363  Ø35Ø           LDHA
Ø6364  Ø361           LDLB
Ø6365  Ø1Ø4           JPUN     /WAIT FOR ANOTHER
Ø6366  6161           KYWAT1   /TELETYPE CGARACTER.
Ø6367  ØØØØ           Ø
Ø637Ø  Ø25Ø  NOMORE,  XORA     /NOT A C FOR CONTINUE SCAN
Ø6371  Ø114           LXMA     /A ØØØ IS A TERMINATOR
Ø6372  ØØØ7           RTUN
```

```
                    /THIS IS THE EXECUTIVE

        2400                *2400
02400   0106  NXTCMD, JSUN      /GET A TELETYPE CHARACTER.
02401   3120          TTYIN
02402   0000          0
02403   0074          COMI
02404   0322          322       /R=REPEAT
02405   0150          JPTZ      /RUN THROUGH D.O.S. USING THE
02406   4635          REPEAT    /ALREADY ESTABLISHED OPERATING
02407   0000          0         /PARAMETERS.
02410   0074          COMI
02411   0302          302       /B=DRAW A BOX AND TICS.
02412   0150          JPTZ      /WE DO NOT GET BACK TO THE
02413   2721          MORBOX    /EXECUTIVE. YOU HAVE TO
02414   0000          0         /PRESS RESET.
02415   0074          COMI
02416   0313          313       /K=KILL THE DARK CURRENT
02417   0110          JPFZ
02420   2437          NOK
02421   0000          0
02422   0056          LDHI
02423   0004          004
02424   0066          LDLI
02425   0000          000
02426   0076  NZERO,  LDMI
02427   0000          000
```

```
02430  0060          INCL
02431  0110          JPFZ
02432  2426          NZERO
02433  0000          0
02434  0104          JPUN
02435  2400          NXTCMD
02436  0000          0
02437  0074  NOK,    COMI
02440  0303          303      /C=CALIBRATE
02441  0110          JPFZ
02442  2452          NOCAL
02443  0000          0
02444  0106          JSUN     /GET A SPECTRA, DETERMINE
02445  4010          BASE     /THE BCC'S, MULTIPLY THE
02446  0000          0        /THE SPECTRAL DATA BY THE BCC'S
02447  0104          JPUN     /AND DISPLAY THE RESULTS.
02450  2400          NXTCMD
02451  0000          0
02452  0074  NOCAL,  COMI
02453  0332          332      /Z=START D.O.S.
02454  0150          JPTZ
02455  4110          SPECTR
02456  0000          0
02457  0074          COMI
02460  0330          330      /X=EXIT TO THE CURSOR ROUTINE
02461  0110          JPFZ
02462  2472          NOCURS
```

```
02463  0000           0
02464  0106           JSUN
02465  6071           CURSE
02466  0000           0
02467  0104           JPUN
02470  2400           NXTCMD
02471  0000           0
02472  0074  NOCURS,  COMI
02473  0320           320      /P=PLOT THE DATA AS A LINE PLOT
02474  0110           JPFZ
02475  2513           NOALPT
02476  0000           0
02477  0106           JSUN
02500  5576           ALLPLT
02501  0000           0
02502  0106  ZXCS,    JSUN
02503  4520           PNUP
02504  0000           0
02505  0250           XORA
02506  0137           XDAC
02507  0135           YDAC
02510  0104           JPUN
02511  2400           NXTCMD
02512  0000           0
02513  0074  NOALPT,  COMI
02514  0323           323      /S=SCALE THE DATA WITH THE
02515  0110           JPFZ     /PREVIOUSLY DETERMINED BASELINE
02516  2526           NOSCAL   /CORRECTION CONSTANTS.
02517  0000           0
```

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```
Ø252Ø  Ø1Ø6            JSUN
Ø2521  4Ø21            SCALE
Ø2522  ØØØØ            Ø
Ø2523  Ø1Ø4            JPUN
Ø2524  24ØØ            NXTCMD
Ø2525  ØØØØ            Ø
Ø2526  ØØ74  NOSCAL,   COMI
Ø2527  Ø3Ø7            3Ø7       /G=GET A SPECTRA
Ø253Ø  Ø11Ø            JPFZ
Ø2531  2541            NOGAS
Ø2532  ØØØØ            Ø
Ø2533  Ø1Ø6            JSUN
Ø2534  5141            GETNXT
Ø2535  ØØØØ            Ø
Ø2536  Ø1Ø4            JPUN
Ø2537  24ØØ            NXTCMD
Ø254Ø  ØØØØ            Ø
Ø2541  ØØ74  NOGAS,    COMI
Ø2542  Ø3Ø4            3Ø4       /D=GO TO ODT
Ø2543  Ø15Ø            JPTZ
Ø2544  ØØ7Ø            ODT
Ø2545  ØØØØ            Ø
Ø2546  ØØ74            COMI
Ø2547  Ø315            315
Ø255Ø  Ø15Ø            JPTZ
Ø2551  314Ø            PANDT
```

```
Ø2552  ØØØØ            Ø
Ø2553  ØØ74  NOTM,     COMI
Ø2554  Ø317            317      /O=POINT PLOT !
Ø2555  Ø15Ø            JPTZ
Ø2556  2651            POINT
Ø2557  ØØØØ            Ø
Ø256Ø  ØØ74            COMI
Ø2561  Ø324            324      /T=GET THE DARK CURRENT
Ø2562  Ø11Ø            JPFZ
Ø2563  2612            NOT
Ø2564  ØØØØ            Ø
Ø2565  Ø1Ø6            JSUN
Ø2566  515Ø            RETCON
Ø2567  ØØØØ            Ø
Ø257Ø  ØØ66            LDLI
Ø2571  ØØØØ            ØØØ
Ø2572  ØØ56  MOVEIT,   LDHI
Ø2573  ØØ17            Ø17
Ø2574  Ø116            LXAM
Ø2575  ØØ56            LDHI
Ø2576  ØØØ4            ØØ4
Ø2577  Ø114            LXMA
Ø26ØØ  ØØ6Ø            INCL
Ø26Ø1  Ø11Ø            JPFZ
Ø26Ø2  2572            MOVEIT
Ø26Ø3  ØØØØ            Ø
Ø26Ø4  Ø1Ø6            JSUN
Ø26Ø5  5113            DISPLA
Ø26Ø6  ØØØØ            Ø
```

```
Ø2607  Ø1Ø4            JPUN
Ø261Ø  24ØØ            NXTCMD
Ø2611  ØØØØ            Ø
Ø2612  ØØ24  NOT,      SUBI     /SEE IF THE USER TYPED IN
Ø2613  Ø26Ø            26Ø      /THE NUMBERS 1-3.
Ø2614  ØØ74            COMI
Ø2615  ØØØ4            ØØ4
Ø2616  Ø1ØØ            JPFC
Ø2617  24ØØ            NXTCMD   /IT WASN'T 1-3, SO IGNORE IT.
Ø262Ø  ØØØØ            Ø
Ø2621  ØØØ4            ADDI     /ADD Ø2Ø TO THE NUMBER TO
Ø2622  ØØ2Ø            Ø2Ø      /CREATE THE PROPER HI ADDRESS.
Ø2623  Ø35Ø            LDHA
Ø2624  ØØ66            LDLI
Ø2625  ØØØØ            ØØØ
Ø2626  Ø116  GETPNT,   LXAM     /GET A DATA VALUE
Ø2627  Ø335            LDDH     /SAVE THE HI ADDRESS
Ø263Ø  ØØ56            LDHI
Ø2631  ØØ17            Ø17
Ø2632  Ø114            LXMA     /AND SAVE IT FROM Ø17 ØØØ-377.
Ø2633  ØØ6Ø            INCL     /ANY MORE DATA TO TRANSFER ?
Ø2634  Ø15Ø            JPTZ     /NO, DISPLAY THE DATA
Ø2635  2643            DIT
Ø2636  ØØØØ            Ø
Ø2637  Ø353            LDHD     /YES, GET THE HI POINTER.
Ø264Ø  Ø1Ø4            JPUN     /AND TRANSFER ANOTHER WORD.
```

```
02641   2626            GETPNT
02642   0000            0
02643   0106    DIT,    JSUN    /NOW DISPLAY THE NEW DATA
02644   5113            DISPLA
02645   0000            0
02646   0104            JPUN
02647   2400            NXTCMD
02650   0000            0
02651   0006    POINT,  LDAI    /O=POINT PLOT THE DATA.
02652   0047            BUFF47
02653   0171            DS      /DISABLE THE DISPLAY BUFFER
02654   0173            IOP1
02655   0106            JSUN    /AND ENABLE THE PLOTTER.
02656   5370            ENABLE
02657   0000            0
02660   0056            LDHI
02661   0017            017
02662   0066            LDLI
02663   0000            000
02664   0106            JSUN
02665   4520            PNUP
02666   0000            0
02667   0106            JSUN
02670   4502            WAIT1
02671   0000            0
02672   0116    ZXC,    LXAM
02673   0135            YDAC
```

```
02674  0306           LDAL
02675  0137           XDAC
02676  0106           JSUN
02677  6143           CLKWAT  /WAIT FOR THE RC CLOCK
02700  0000           0
02701  0106           JSUN    /PLOT THE POINT
02702  4476           PNDWN
02703  0000           0
02704  0106           JSUN
02705  4520           PNUP
02706  0000           0
02707  0106           JSUN
02710  6143           CLKWAT  /WAIT FOR THE RC CLOCK
02711  0000           0
02712  0060           INCL    /ANY MORE DATA TO PLOT ?
02713  0110           JPFZ    /YES, GET ANOTHER POINT.
02714  2672           ZXC
02715  0000           0
02716  0104           JPUN
02717  2502           ZXCS
02720  0000           0
02721  0006  MORBOX,  LDAI    /PLOT A "BOX" AND TICS.
02722  0047           BUFF47
02723  0171           DS
02724  0173           IOP1
02725  0106           JSUN
02726  5370           ENABLE
02727  0000           0
```

```
02730  0104            JPUN
02731  4373            BOX
02732  0000            0

                /BINBCD CONVERTS THE BINARY VALUE IN "A"
                /TO BCD VALUES IN D,E AND C AND THEN
                /TYPES OUT THE ASCII VALUES ON THE
                /TELETYPE.

02733  0024  BINBCD,   SUBI
02734  0144            144
02735  0140            JPTC
02736  2744            TENS
02737  0000            0
02740  0030            INCD
02741  0104            JPUN
02742  2733            BINBCD
02743  0000            0
02744  0004  TENS,     ADDI
02745  0144            144
02746  0024  TEN,      SUBI
02747  0012            012
02750  0140            JPTC
02751  2757            UNITS
02752  0000            0
02753  0040            INCE
```

```
Ø2754   Ø1Ø4            JPUN
Ø2755   2746            TEN
Ø2756   ØØØØ            Ø
Ø2757   ØØØ4   UNITS,   ADDI
Ø276Ø   ØØ12            Ø12
Ø2761   Ø32Ø            LDCA
Ø2762   Ø1Ø6            JSUN
Ø2763   3ØØ6            OCTOUT
Ø2764   ØØØØ            Ø
Ø2765   ØØØ7            RTUN

               /"PUNCH" PUNCHES OUT TBS AND THE USER
               /SELECTED ARRAY NUMBERS (IN THAT ORDER)
               /ON PAPER TAPE.

Ø2766   ØØ66   PUNCH,   LDLI
Ø2767   Ø1ØØ            1ØØ
Ø277Ø   ØØ56            LDHI
Ø2771   ØØ1Ø            Ø1Ø
Ø2772   Ø116   PMORE,   LXAM
Ø2773   Ø146            LXDM     /MUST BE IN D TO TYPE IT OUT
Ø2774   ØØ74            COMI
Ø2775   Ø377            377
Ø2776   ØØ53            RTTZ     /EVERYTHING HAS BEEN PUNCHED OUT
Ø2777   Ø1Ø6            JSUN
Ø3ØØØ   3127            TTYOUT
Ø3ØØ1   ØØØØ            Ø
Ø3ØØ2   ØØ6Ø            INCL
Ø3ØØ3   Ø1Ø4            JPUN
```

```
03004  2772          PMORE
03005  0000          0

              /"OCTOUT" IS USED BY BINBCD TO TYPE
              /OUT THE CONTENTS OF D,E AND C AS ASCII
              /VALUES ON THE TELETYPE.

03006  0303   OCTOUT, LDAD
03007  0004          ADDI
03010  0260          260
03011  0330          LDDA
03012  0106          JSUN
03013  3127          TTYOUT
03014  0000          0
03015  0304          LDAE
03016  0004          ADDI
03017  0260          260
03020  0330          LDDA
03021  0106          JSUN
03022  3127          TTYOUT
03023  0000          0
03024  0302          LDAC
03025  0004          ADDI
03026  0260          260
03027  0330          LDDA
03030  0106          JSUN
03031  3127          TTYOUT
03032  0000          0
```

```
03033  0007          RTUN

              /"LDTR" IS USED TO PUNCH OUT 6.4 INCHES
              /OF BLANK PAPER TAPE BOTH BEFORE AND AFTER
              /A SEPARATION HAS BEEN RUN.

03034  0016  LDTR,   LDBI
03035  0100          100
03036  0036          LDDI
03037  0000          000
03040  0106          JSUN
03041  3127          TTYOUT
03042  0000          0
03043  0011          DECB
03044  0110          JPFZ
03045  3036          LDTR+2
03046  0000          0
03047  0007          RTUN

              /"CHKIT" IS USED TO CHECK THE DATA VALUES
              /BEING READ FROM THE BIOMATION. IF ANY OF
              /THE DATA VALUES ARE GREATER THAN 074, THE
              /TELETYPE BELL WILL BE RUNG AND ANOTHER
              /SPECTRA ACQUIRED.      IF THE BELL IS RUNG, THE
              /USER MUST TURN THE BIOMATION'S OFFSET CONTROL
              /COUNTERCLOCKWISE, UNTIL THE BELL IS NO LONGER
              /RUNG.
```

```
Ø3Ø5Ø  ØØ56  CHKIT,  LDHI
Ø3Ø51  ØØ17          Ø17
Ø3Ø52  ØØ66          LDLI
Ø3Ø53  ØØØØ          ØØØ
Ø3Ø54  Ø116  NXTCHK, LXAM
Ø3Ø55  ØØ74          COMI
Ø3Ø56  Ø37Ø          37Ø     /MAXIMUM # ALLOWABLE.
Ø3Ø57  Ø1ØØ          JPFC
Ø3Ø6Ø  3Ø71          NOGO
Ø3Ø61  ØØØØ          Ø
Ø3Ø62  ØØ6Ø          INCL
Ø3Ø63  Ø11Ø          JPFZ
Ø3Ø64  3Ø54          NXTCHK
Ø3Ø65  ØØØØ          Ø
Ø3Ø66  Ø1Ø4          JPUN
Ø3Ø67  4Ø16          DATOK
Ø3Ø7Ø  ØØØØ          Ø
Ø3Ø71  ØØ36  NOGO,   LDDI
Ø3Ø72  Ø2Ø7          2Ø7
Ø3Ø73  Ø1Ø6          JSUN
Ø3Ø74  3127          TTYOUT
Ø3Ø75  ØØØØ          Ø
Ø3Ø76  Ø1Ø4          JPUN
Ø3Ø77  4Ø1Ø          BASE
Ø31ØØ  ØØØØ          Ø
```

```
03101  0106  TEST,   JSUN    /THIS IS FOR TESTING
03102  5150          RETCON  /PURPOSES ONLY.
03103  0000          0
03104  0106          JSUN
03105  4021          SCALE
03106  0000          0
03107  0115  CVB,    SR1
03110  0044          ANDI
03111  0001          NE555
03112  0110          JPFZ
03113  3107          CVB
03114  0000          0
03115  0104          JPUN
03116  3101          TEST
03117  0000          0

03120  0103  TTYIN,  INP1    /INPUT A TELETYPE CHARACTER
03121  0032          RARC
03122  0100          JPFC
03123  3120          TTYIN
03124  0000          0
03125  0101          INP0
03126  0330          LDDA
03127  0103  TTYOUT, INP1    /PRINT A CHARACTER
03130  0032          RARC
03131  0032          RARC
03132  0100          JPFC
03133  3127          TTYOUT
03134  0000          0
```

```
03135  0303        LDAD
03136  0121        OUT0
03137  0007        RTUN
```

```
03140  0106  PANDT,  JSUN
03141  3234          CRLF
03142  0000          0
03143  0056          LDHI
03144  0017          017
03145  0066          LDLI
03146  0000          000
03147  0016          LDBI
03150  0014          014
03151  0106          JSUN
03152  3217          POUT
03153  0000          0
03154  0011          DECB
03155  0110          JPFZ
03156  3165          NOROW
03157  0000          0
03160  0016          LDBI
03161  0014          014
03162  0106          JSUN
03163  3234          CRLF
03164  0000          0
03165  0060  NOROW,  INCL
03166  0110          JPFZ
03167  3151          PANDT+11
03170  0000          0
```

```
Ø3171  Ø1Ø6           JSUN
Ø3172  3234           CRLF
Ø3173  ØØØØ           Ø
Ø3174  Ø1Ø6           JSUN
Ø3175  3234           CRLF
Ø3176  ØØØØ           Ø
Ø3177  Ø1Ø6           JSUN
Ø32ØØ  3Ø34           LDTR
Ø32Ø1  ØØØØ           Ø
Ø32Ø2  Ø1Ø6  TAPEIT,  JSUN
Ø32Ø3  3217           POUT
Ø32Ø4  ØØØØ           Ø
Ø32Ø5  ØØ6Ø           INCL
Ø32Ø6  Ø11Ø           JPFZ
Ø32Ø7  32Ø2           TAPEIT
Ø321Ø  ØØØØ           Ø
Ø3211  Ø1Ø6           JSUN
Ø3212  3Ø34           LDTR
Ø3213  ØØØØ           Ø
Ø3214  Ø1Ø4           JPUN
Ø3215  24ØØ           NXTCMD
Ø3216  ØØØØ           Ø
Ø3217  Ø25Ø  POUT,    XORA
Ø322Ø  Ø32Ø           LDCA
Ø3221  Ø33Ø           LDDA
Ø3222  Ø34Ø           LDEA
Ø3223  Ø116           LXAM
Ø3224  Ø1Ø6           JSUN
Ø3225  2733           BINBCD
```

```
03226  0000          0
03227  0036          LDDI
03230  0240          240
03231  0104          JPUN
03232  3127          TTYOUT
03233  0000          0
03234  0036  CRLF,   LDDI
03235  0215          215
03236  0106          JSUN
03237  3127          TTYOUT
03240  0000          0
03241  0036          LDDI
03242  0212          212
03243  0104          JPUN
03244  3127          TTYOUT
03245  0000          0

             /BASEC CALCULATES THE DOUBLE PRECISION
             /BASELINE CORRECTION CONSTANTS.  THESE
             /DATA VALUES ARE STORED FROM 6400 TO 7377
             /015 000 - 016 377. THE LSB IS STORED
             /FIRST THEN THE MSB.

03246  0056  BASEC,  LDHI
03247  0010          010
03250  0066          LDLI
03251  0032          032
```

```
Ø3252  ØØ76        LDMI
Ø3253  ØØØØ        ØØØ
Ø3254  ØØ6Ø        INCL
Ø3255  ØØ76        LDMI
Ø3256  ØØ15        Ø15
Ø3257  ØØ6Ø        INCL
Ø326Ø  ØØ76        LDMI
Ø3261  ØØØØ        ØØØ
Ø3262  ØØ66        LDLI
Ø3263  ØØØØ        ØØØ
Ø3264  ØØ56  MP,   LDHI
Ø3265  ØØ17        Ø17
Ø3266  Ø136        LXCM
Ø3267  Ø3Ø6        LDAL
Ø327Ø  ØØ66        LDLI
Ø3271  ØØ34        Ø34
Ø3272  ØØ56        LDHI
Ø3273  ØØ1Ø        Ø1Ø
Ø3274  Ø114        LXMA
Ø3275  ØØ36        LDDI
Ø3276  Ø37Ø        37Ø
Ø3277  ØØ46        LDEI
Ø33ØØ  ØØØØ        ØØØ
Ø33Ø1  ØØ16        LDBI
Ø33Ø2  ØØØØ        ØØØ
Ø33Ø3  Ø1Ø6        JSUN
Ø33Ø4  57Ø7        DDIV
Ø33Ø5  ØØØØ        Ø
```

```
Ø33Ø6  ØØ56        LDHI
Ø33Ø7  ØØ1Ø        Ø1Ø
Ø331Ø  ØØ66        LDLI
Ø3311  ØØ32        Ø32
Ø3312  Ø126        LXBM
Ø3313  ØØ6Ø        INCL
Ø3314  Ø136        LXCM
Ø3315  Ø361        LDLB
Ø3316  Ø352        LDHC
Ø3317  Ø154        LXME
Ø332Ø  Ø1Ø6        JSUN
Ø3321  4252        INCRLH
Ø3322  ØØØØ        Ø
Ø3323  Ø144        LXMD
Ø3324  Ø1Ø6        JSUN
Ø3325  4252        INCRLH
Ø3326  ØØØØ        Ø
Ø3327  Ø326        LDCL
Ø333Ø  Ø335        LDDH
Ø3331  ØØ56        LDHI
Ø3332  ØØ1Ø        Ø1Ø
Ø3333  ØØ66        LDLI
Ø3334  ØØ32        Ø32
Ø3335  Ø134        LXMC
Ø3336  ØØ6Ø        INCL
Ø3337  Ø144        LXMD
Ø334Ø  ØØ6Ø        INCL
```

```
Ø3341  Ø126           LXBM
Ø3342  Ø361           LDLB
Ø3343  ØØ6Ø           INCL
Ø3344  Ø11Ø           JPFZ
Ø3345  3264           MP
Ø3346  ØØØØ           Ø
Ø3347  ØØØ7           RTUN

              /DATCRT MULTIPLIES THE CURRENT SPECTRA
              /STORED FROM 74ØØ - 7777 BY THE PREVIOUSLY
              /DETERMINED BASELINE CORRECTION CONSTANTS.
              /THE MSB OF THE DOUBLE PRECISION RESULT
              /IS THEN STORED IN MEMORY FROM 74ØØ - 7777
              /(Ø17 ØØØ - Ø17 377).

Ø335Ø  ØØ56   DATCRT, LDHI
Ø3351  ØØ1Ø           Ø1Ø
Ø3352  ØØ66           LDLI
Ø3353  ØØ32           Ø32
Ø3354  ØØ76           LDMI
Ø3355  ØØØØ           ØØØ
Ø3356  ØØ6Ø           INCL
Ø3357  ØØ76           LDMI
Ø336Ø  ØØ15           Ø15
Ø3361  ØØ6Ø           INCL
Ø3362  ØØ76           LDMI
Ø3363  ØØØØ           ØØØ
Ø3364  ØØ66           LDLI
```

```
Ø3365  ØØØØ          ØØØ
Ø3366  ØØ56  MP1,    LDHI
Ø3367  ØØ17          Ø17
Ø337Ø  Ø156          LXEM
Ø3371  Ø316          LDBL
Ø3372  ØØ56          LDHI
Ø3373  ØØ1Ø          Ø1Ø
Ø3374  ØØ66          LDLI
Ø3375  ØØ34          Ø34
Ø3376  Ø124          LXMB
Ø3377  ØØ61          DECL
Ø34ØØ  Ø136          LXCM
Ø34Ø1  ØØ61          DECL
Ø34Ø2  Ø146          LXDM
Ø34Ø3  Ø352          LDHC
Ø34Ø4  Ø363          LDLD
Ø34Ø5  Ø136          LXCM
Ø34Ø6  Ø1Ø6          JSUN
Ø34Ø7  4252          INCRLH
Ø341Ø  ØØØØ          Ø
Ø3411  Ø126          LXBM
Ø3412  Ø1Ø6          JSUN
Ø3413  4252          INCRLH
Ø3414  ØØØØ          Ø
Ø3415  Ø3Ø6          LDAL
Ø3416  Ø335          LDDH
Ø3417  ØØ56          LDHI
Ø342Ø  ØØ1Ø          Ø1Ø
```

```
Ø3421  ØØ66          LDLI
Ø3422  ØØ32          Ø32
Ø3423  Ø114          LXMA
Ø3424  ØØ6Ø          INCL
Ø3425  Ø144          LXMD
Ø3426  ØØ36          LDDI
Ø3427  ØØØØ          ØØØ
Ø343Ø  Ø1Ø6          JSUN
Ø3431  6ØØ5          DMUL
Ø3432  ØØØØ          Ø
Ø3433  ØØ56          LDHI
Ø3434  ØØ1Ø          Ø1Ø
Ø3435  ØØ66          LDLI
Ø3436  ØØ34          Ø34
Ø3437  Ø116          LXAM
Ø344Ø  Ø36Ø          LDLA
Ø3441  ØØ56          LDHI
Ø3442  ØØ17          Ø17
Ø3443  Ø144          LXMD
Ø3444  ØØ6Ø          INCL
Ø3445  Ø11Ø          JPFZ
Ø3446  3366          MP1
Ø3447  ØØØØ          Ø
Ø345Ø  ØØØ7          RTUN
             $
```

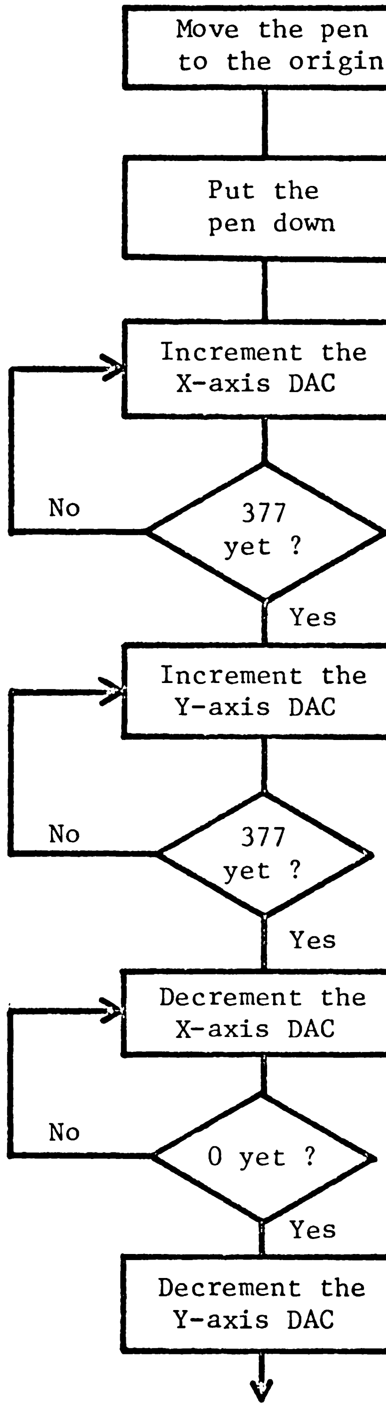
AGAIN	5620	MAXX	4345	PNT1	5676
ALLPLT	5576	MAXY	4355	PNUP	4520
ARROUT	4650	MORBOX	2721	POINT	2651
ARRY	4175	MORDSP	5122	POUT	3217
BASE	4010	MOVEIT	2572	PUNCH	2766
BASEC	3246	MP	3264	QPLOT	4734
BASPNT	4036	MP1	3366	RDRWAT	5350
BCDBIN	5654	NC	5773	REPEAT	4635
BINBCD	2733	NC1	6060	RETCON	5150
BOX	4373	NMBR	4256	RET1	5173
CALIB	4270	NMSPC	5675	SAVE	6205
CHKIT	3050	NOALPT	2513	SCALE	4021
CLEAN	5667	NOAP	4747	SERRTC	5042
CLKWAT	6143	NOCAL	2452	SPECTR	4110
CMPRS	5406	NOCR	4530	SRTC	4043
CONTIN	6233	NOCURS	2472	TAPEIT	3202
CRLF	3234	NOGAS	2541	TBSM	4077
CURSE	6071	NOGO	3071	TEMPD	4040
CVB	3107	NOINC	5016	TEN	2746
C0	4100	NOK	2437	TENS	2744
C1	4101	NOMORE	6370	TERMIT	4674
C2	4102	NOPLOT	5070	TEST	3101
C2BIT	5301	NOROW	3165	TICS	4547
C3	4103	NOSAVE	4777	TIMER	4705
C4	4104	NOSCAL	2526	TTYIN	3120
C5	4105	NOT	2612	TTYOUT	3127
C6	4106	NOTM	2553	T2	5706

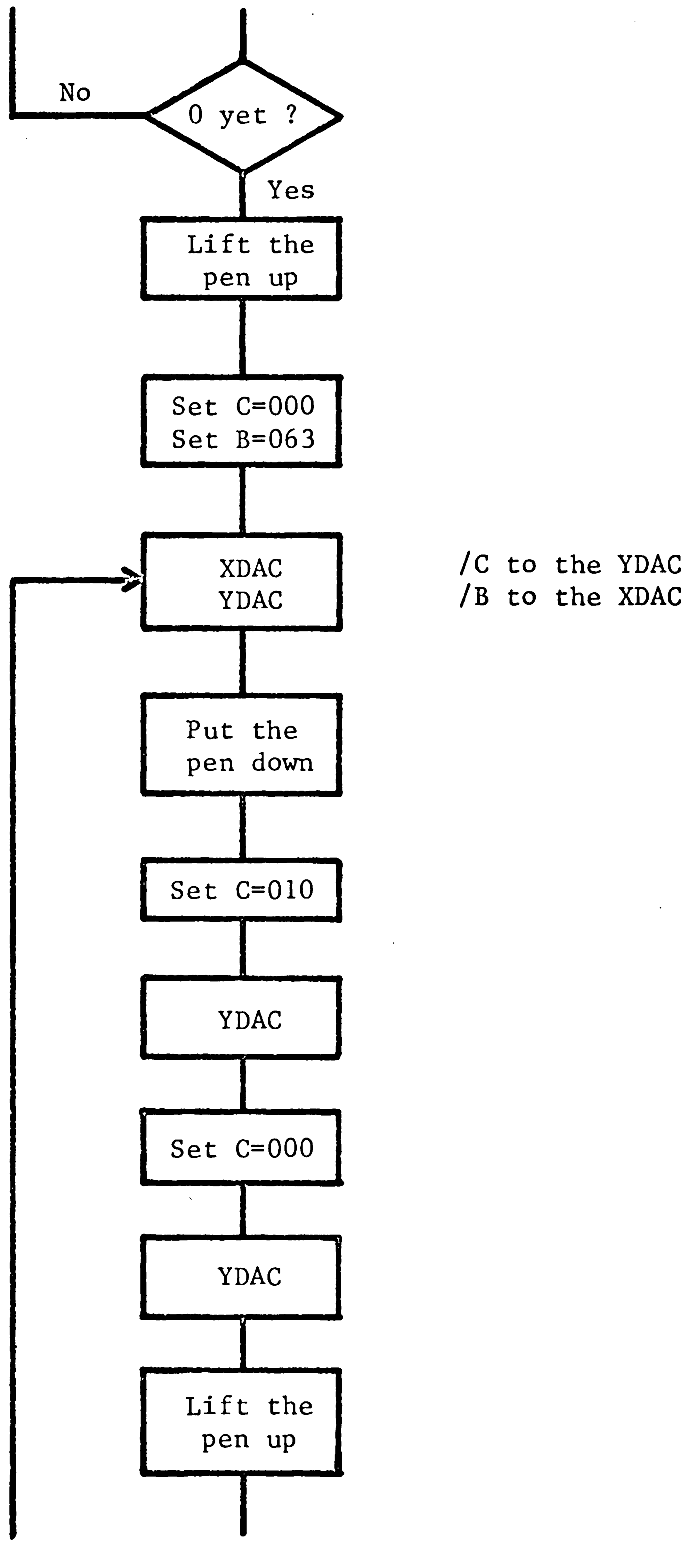
C7	4107	NOVAL	4276	UNITS	2757
DATA	4226	NPSAVE	4763	WAIT1	4502
DATAT	4033	NSCYET	6256	WAIT2	4507
DATCRT	3350	NUMBSA	4032	WAIT3	5203
DATOK	4016	NXBIT	6022	WAVEL	6152
DATPNT	4035	NXLIN	4434	W1	6127
DDIV	5707	NXTAB	5420	W2	6136
DISABL	5375	NXTBIT	5724	XLIN	4406
DISPLA	5113	NXTCHK	3054	XPOS	5575
DIT	2643	NXTCMD	2400	YLIN	4420
DMUL	6005	NXTCP	6133	ZERO	5471
ENABLE	5370	NXTPCH	5076	ZEROIT	4264
FINISH	4621	NXTPOS	5536	ZXC	2672
FOR	6174	NXTPT	5223	ZXCS	2502
GETNXT	5141	NXTSC	6104		
GETPNT	2626	NXTSCP	5130		
GETSPC	4060	NXTSPC	4710		
GOWAIT	4700	NXTTIC	4564		
HIP	4030	NYLIN	4450		
INCRLH	4252	NZERO	2426		
INPUT	4525	OCTOUT	3006		
INTNXT	6113	ORIGIN	4365		
INT1	5026	OUTPUT	4462		
ITIME	5200	PANDT	3140		
KYWAT1	6161	PLTWAT	5630		
LDTR	3034	PMORE	2772		
LISTER	5343	PNDWN	4476		
MASK	4034	PNTPLT	5504		

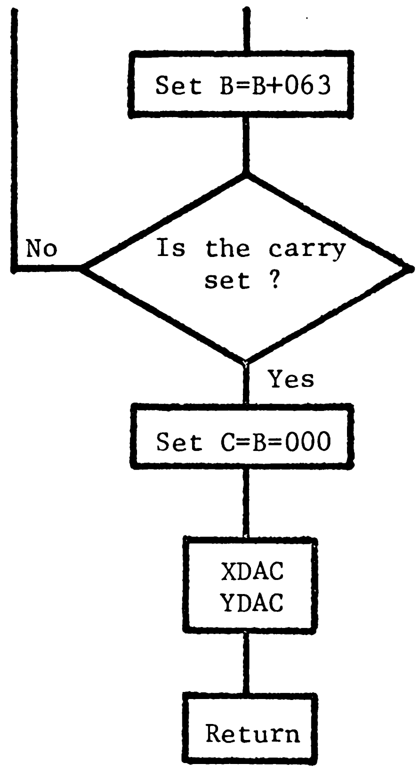
APPENDIX D

This subroutine draws the coordinate system on the X-Y plotter. When completed, five tic marks are then drawn on the X-axis.

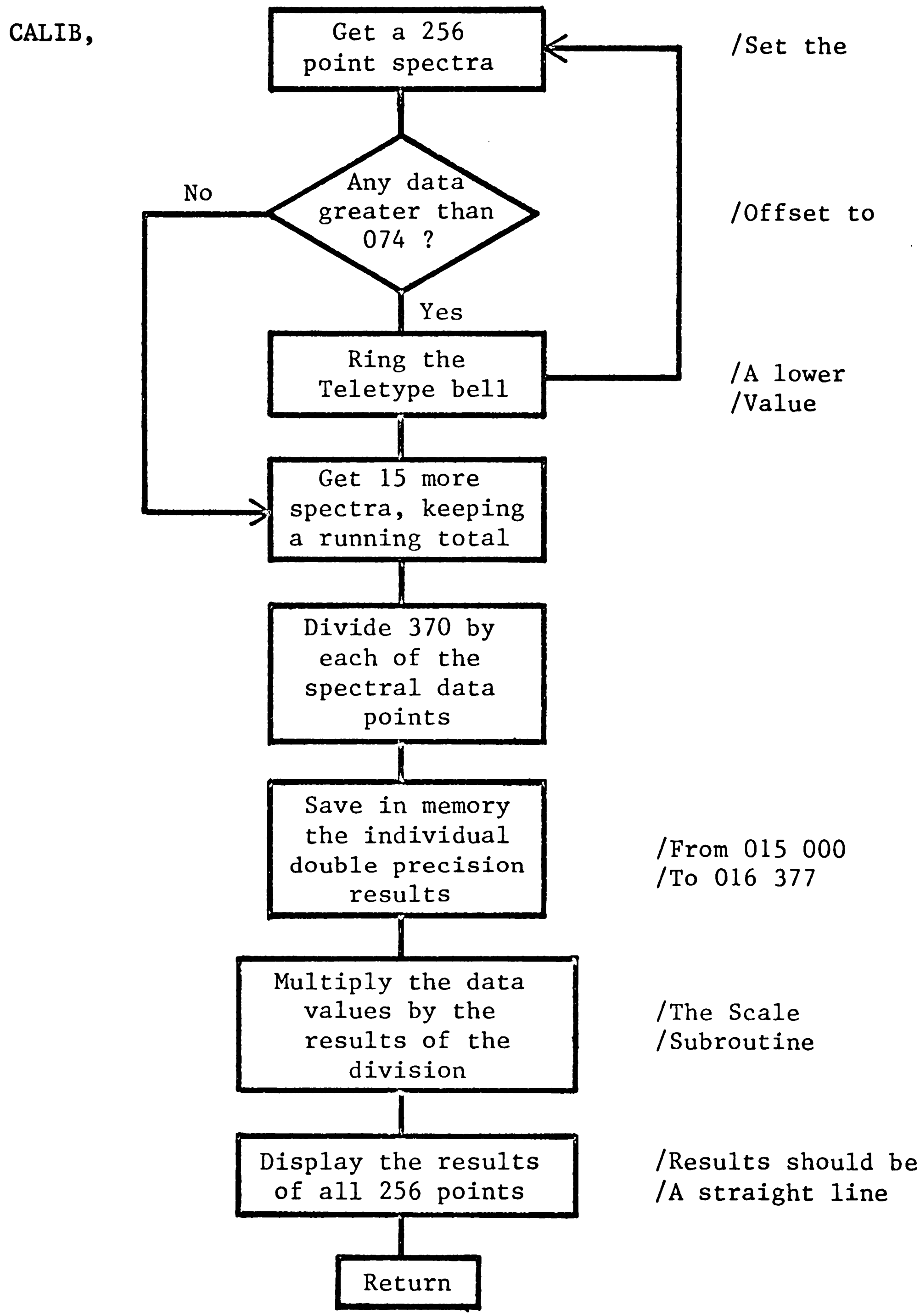
BOX,

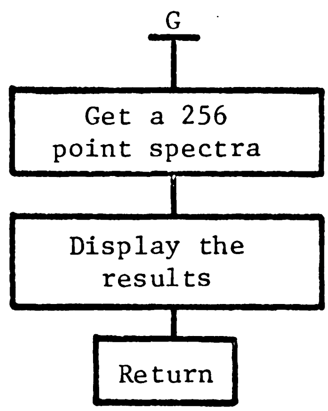



No
0 yet ?
Yes
Lift the pen up
Set C=000
Set B=063
XDAC
YDAC
/C to the YDAC
/B to the XDAC
Put the pen down
Set C=010
YDAC
Set C=000
YDAC
Lift the pen up

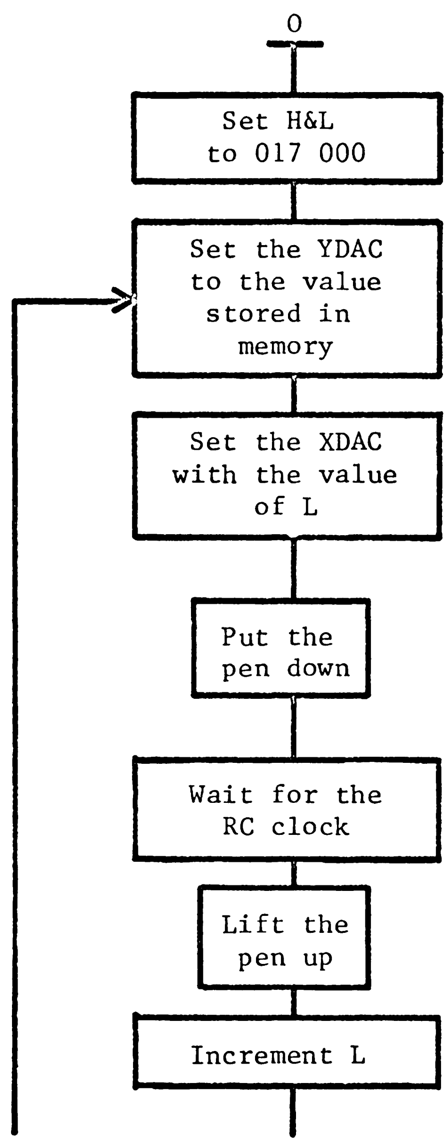

Set B=B+063
No
Is the carry set ?
Yes
Set C=B=000
XDAC
YDAC
Return

The calibrate subroutine calculates the baseline correction constants based on the responsivity of the silicon photodiode array.

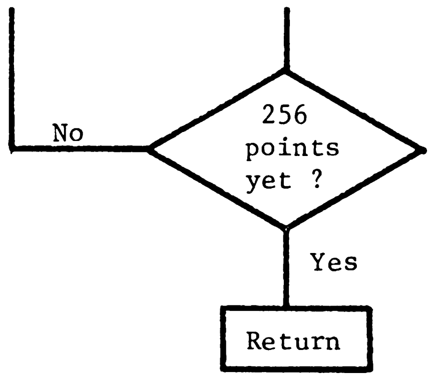




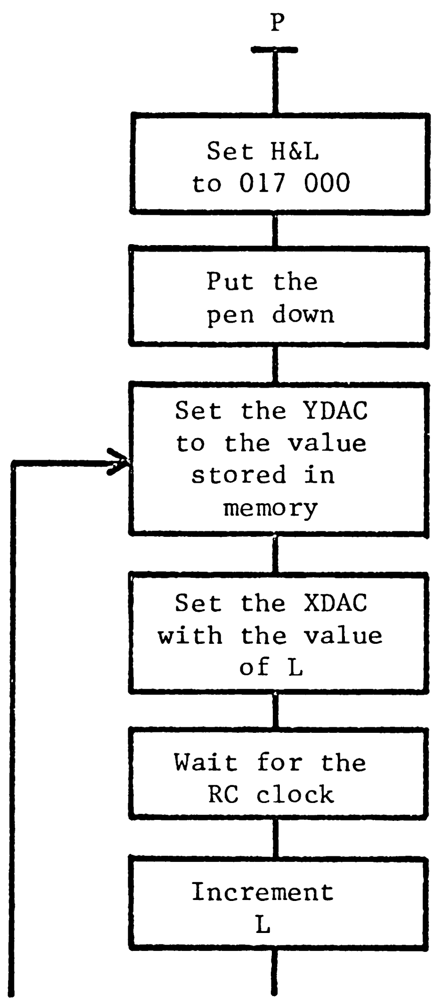
/Get a spectra

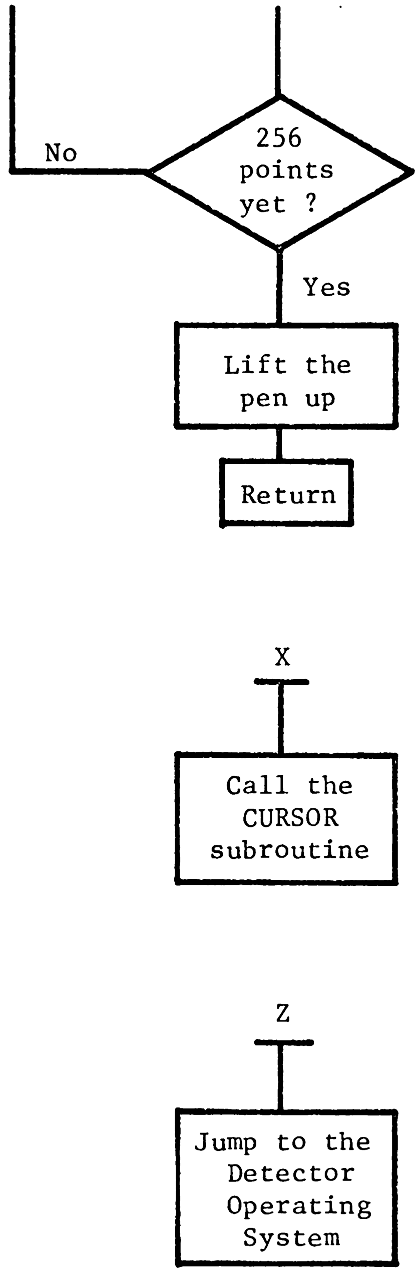


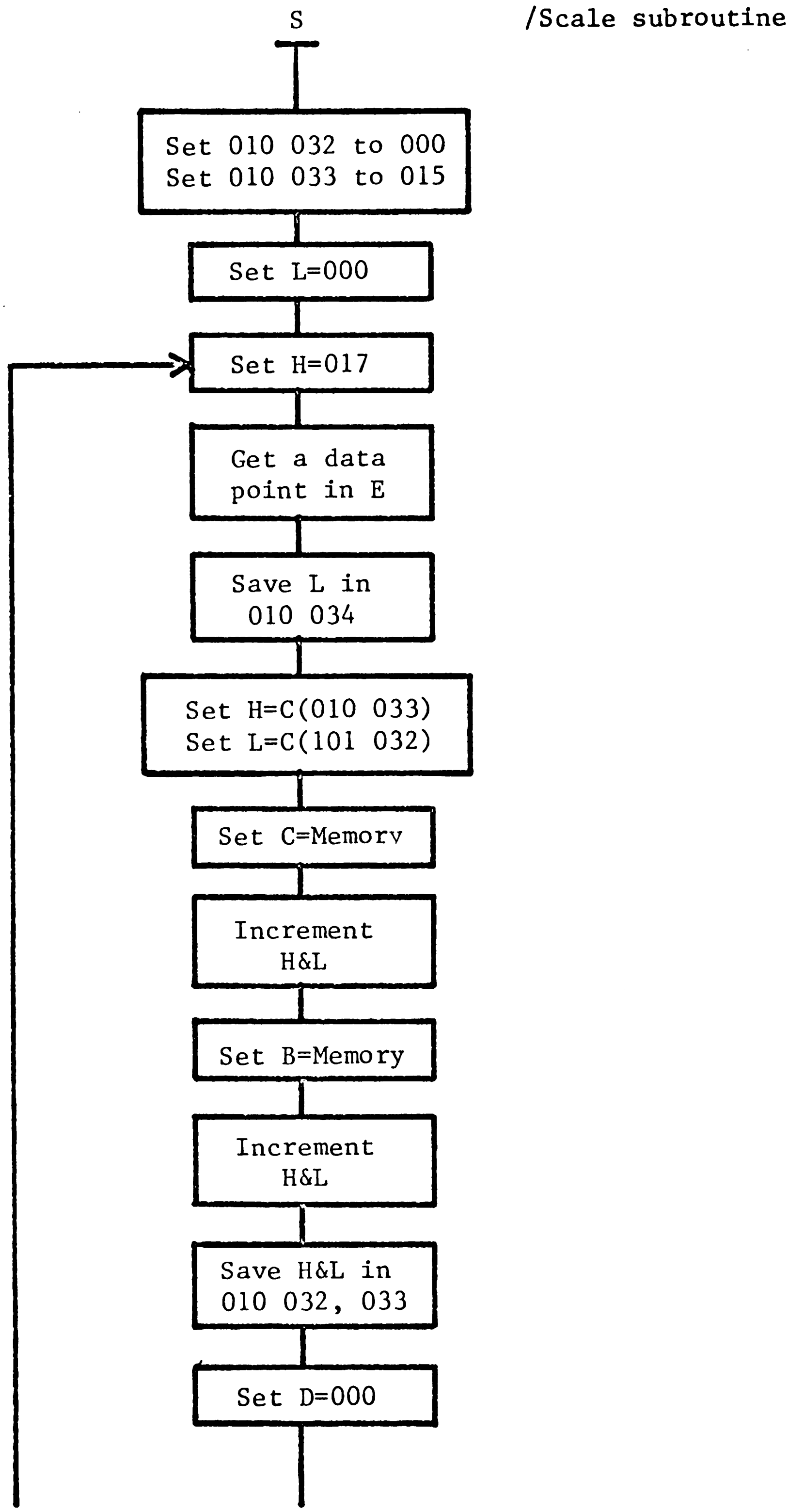
/Point plot

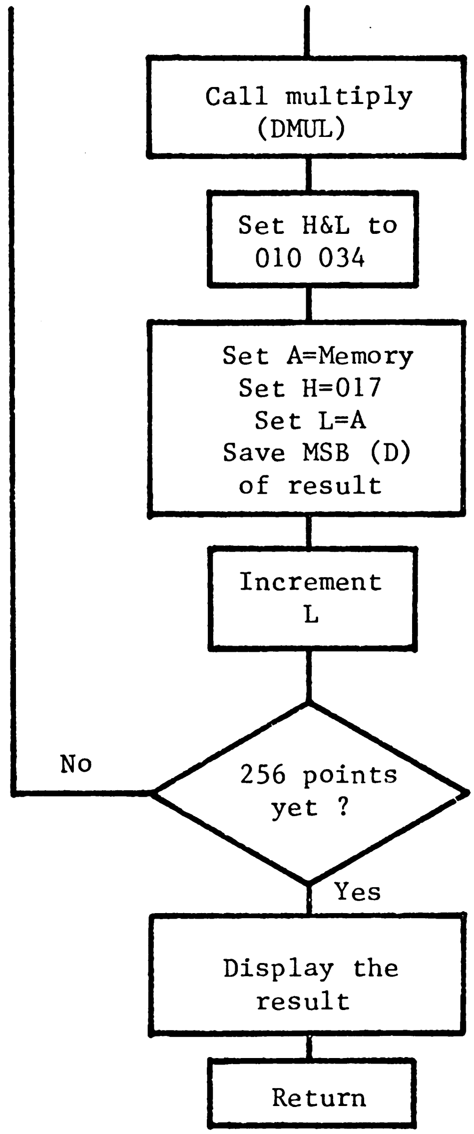

No
256 points yet ?
Yes
Return

/Line plot

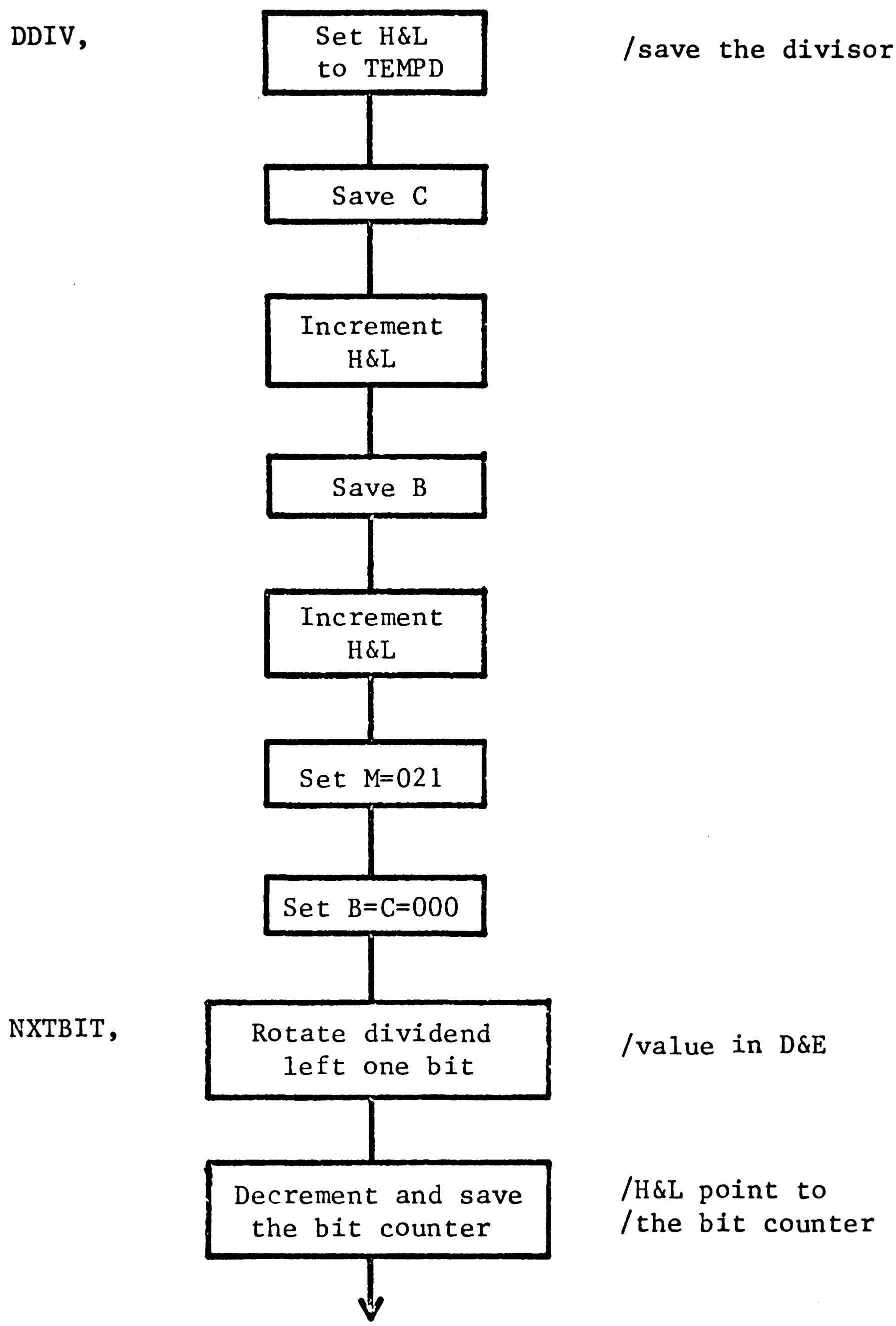

P
Set H&L to 017 000
Put the pen down
Set the YDAC to the value stored in memory
Set the XDAC with the value of L
Wait for the RC clock
Increment L

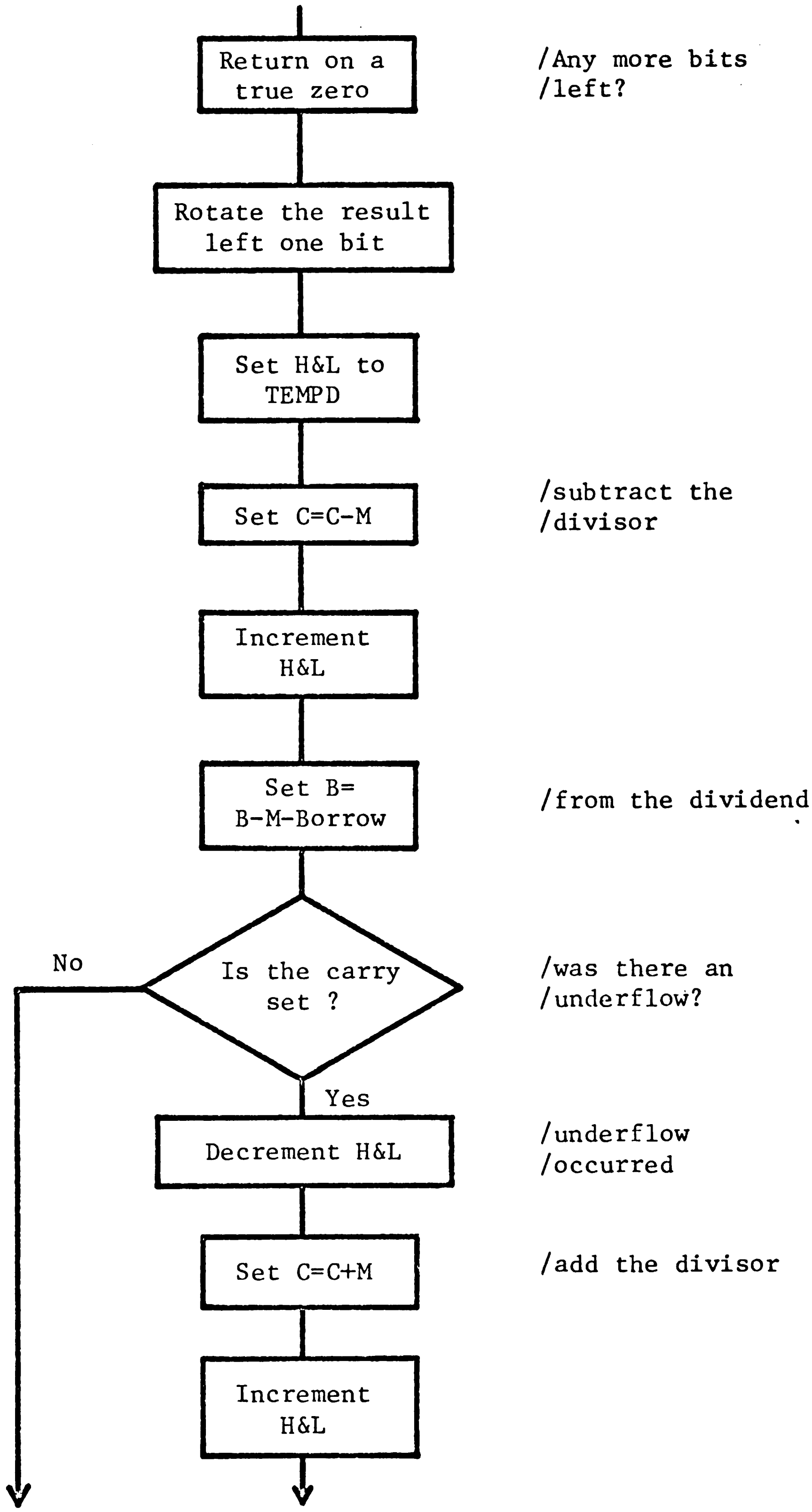

No
256 points yet ?
Yes
Lift the pen up
Return
X
Call the CURSOR subroutine
Z
Jump to the Detector Operating System

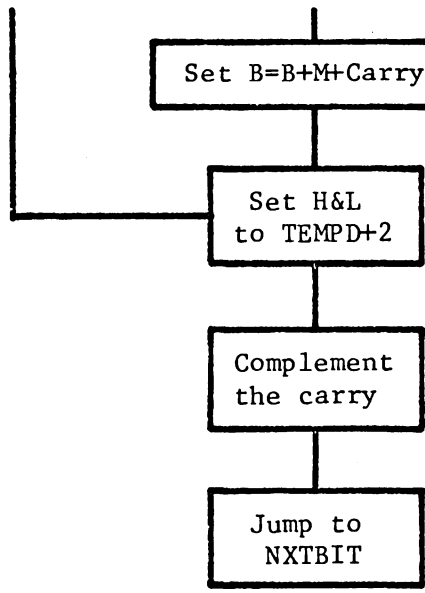

S
/Scale subroutine
Set 010 032 to 000
Set 010 033 to 015
Set L=000
Set H=017
Get a data
point in E
Save L in
010 034
Set H=C(010 033)
Set L=C(101 032)
Set C=Memorv
Increment
H&L
Set B=Memory
Increment
H&L
Save H&L in
010 032, 033
Set D=000


Call multiply (DMUL)
Set H&L to 010 034
Set A=Memory
Set H=017
Set L=A
Save MSB (D) of result
Increment L
256 points yet ?
No
Yes
Display the result
Return

This subroutine divides the 16 bit value in D and E by the 16 bit divisor in B and C, giving a 16 bit result stored in D and E. All numbers are unsigned 16 bit values.

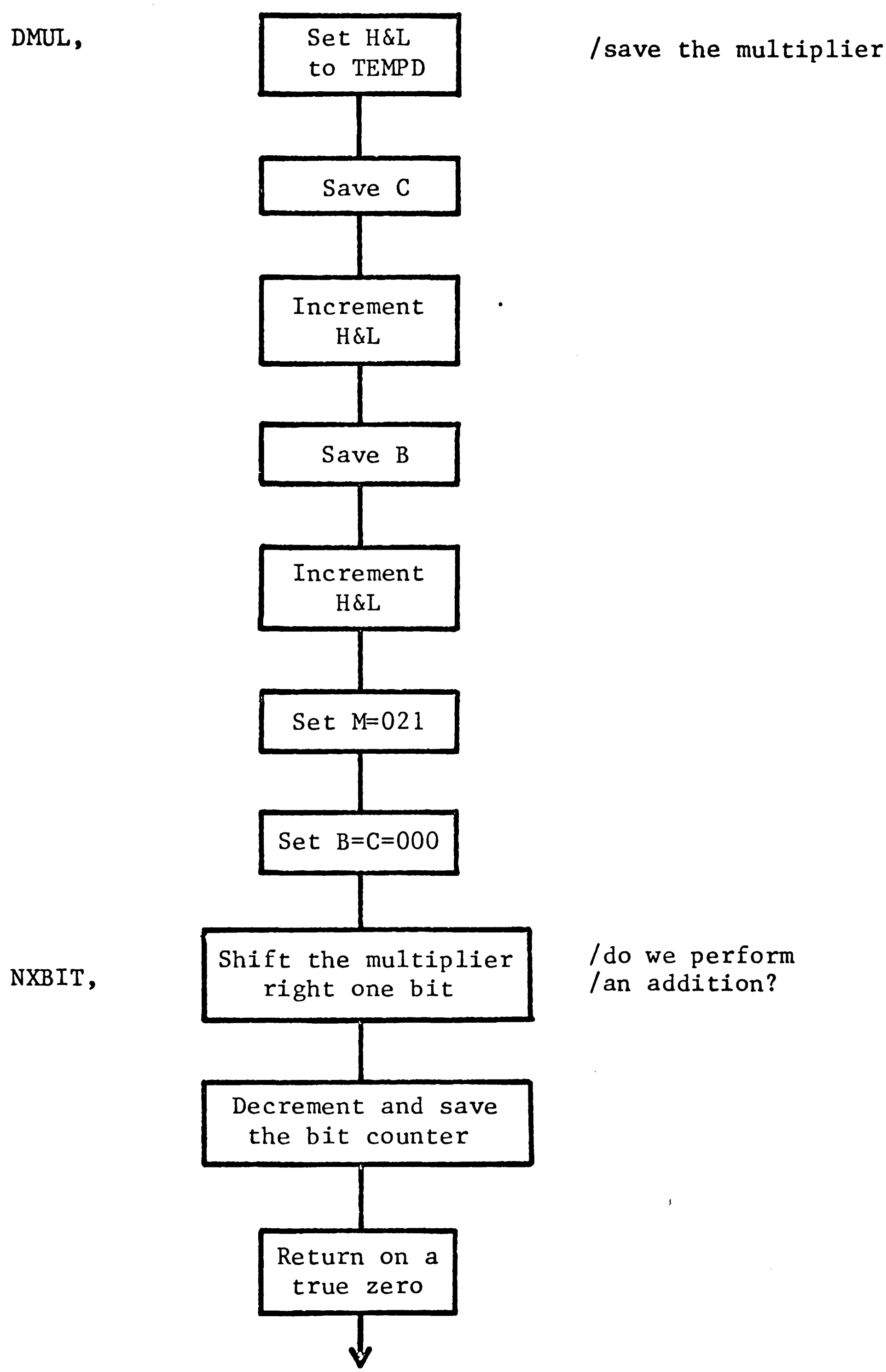


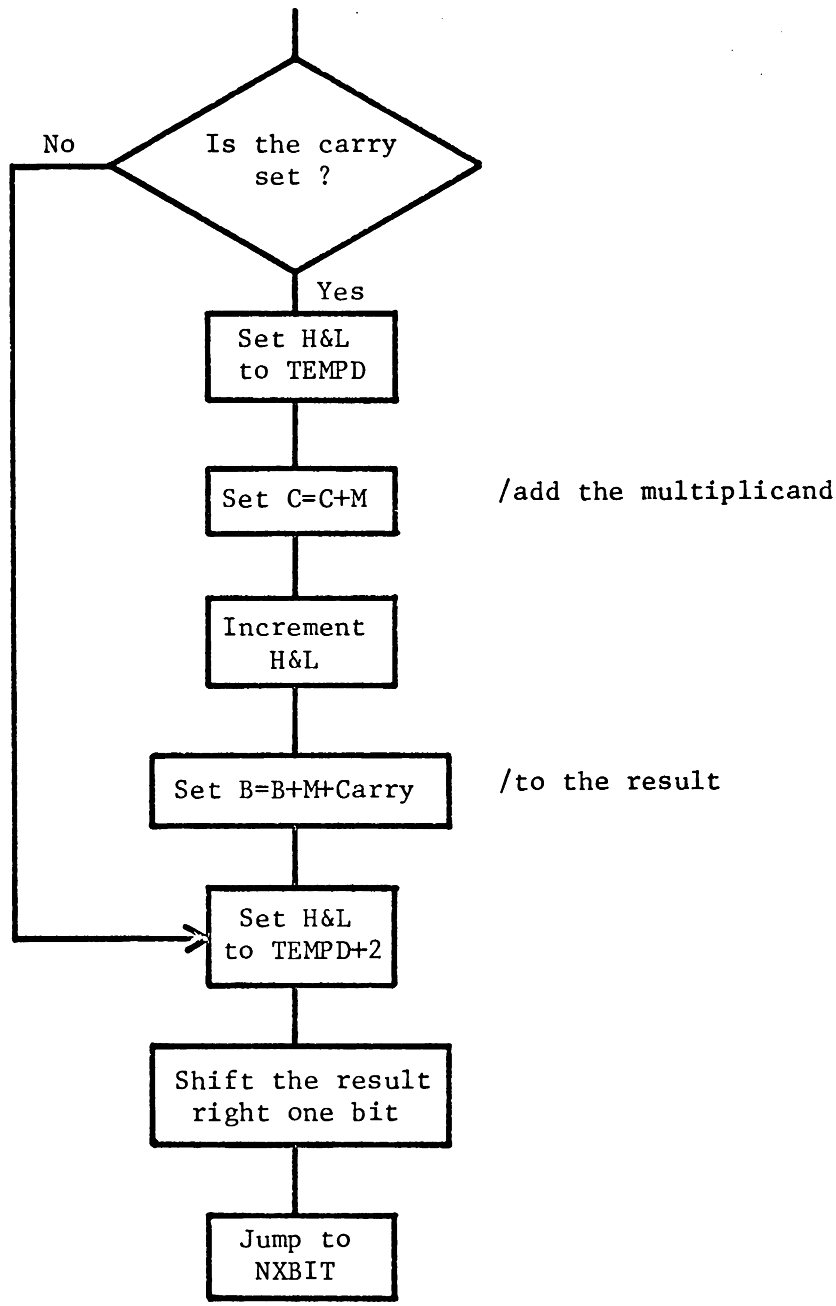

Return on a true zero
/Any more bits /left?
Rotate the result left one bit
Set H&L to TEMPD
Set C=C-M
/subtract the /divisor
Increment H&L
Set B= B-M-Borrow
/from the dividend
No
Is the carry set ?
/was there an /underflow?
Yes
Decrement H&L
/underflow /occurred
Set C=C+M
/add the divisor
Increment H&L



/to the dividend

This subroutine multiplies the 16 bit value in D and E by the 16 bit value in B and C, with the result in D and E.




Is the carry set ?
No
Yes
Set H&L to TEMPD
Set C=C+M
/add the multiplicand
Increment H&L
Set B=B+M+Carry
/to the result
Set H&L to TEMPD+2
Shift the result right one bit
Jump to NXBIT

APPENDIX E

WIRE LIST

This is the backplane wire list for all of the interface electronics involved in the multiwavelength-detector system. This list includes all of the card-to-card connections and all of the card-to-BNC or Molex connections. The first number represents the card slot number and the second represents the edge connector finger number. The letter indicates whether the finger is on the pin (P) or component (C) side of the board.

Signal Name	Cable Card	Device Decoder	Real Time Clock	Biomation Controller	Display Controller
DI0	1/35P	3/30P		10/10C	
DI1	1/34P	3/29P	DATA	10/9C	
DI2	1/33P	3/28P		10/8C	
DI3	1/32P	3/27P	INPUT	10/7C	
DI4	1/31P	3/26P		10/6C	
DI5	1/30P	3/25P	BUS	10/5C	
DI6	1/29P	3/24P		10/4C	
DI7	1/28P	3.23P		10/3C	
A15	1/27P	3/1C			
A14	1/25P	3/2C			
A13	1/24P	3/3C			
A12	1/23P	3/4C			
A11	1/22P	3/5C			

A10	1/21P	3/6C			
A9	1/20P	3/7C			
A8	1/19P				
A7	1/3P		7/8P		13/35P
A6	1/4P		7/7P		13/34P
A5	1/5P	3/6P	7/6P		13/33P
A4	1/6P	3/5P	7/5P		13/32P
A3	1/7P	3/4P	7/4P		13/31P
A2	1/8P	3/3P	7/3P		13/30P
A1	1/9P	3/2P	7/2P		13/29P
A0	1/10P	3/1P	7/1P		13/28P
OUT	1/27P	3/9C	7/12P		13/16P
OUT5	1/14P		7/13C		
OUT6	1/13P		7/11P		13/17P
OUT7	1/12P		7/10P		13/18P
IN	1/11P	3/22P		10/12P	
IN5	1/18P			10/12C	
IN6	1/17P	3/21P			
IN6-1	LSB - RC Clock		3/38P	3/27C	
IN6-2	Biomation Flag		3/37P	10/13C	
IN6-8	MSB - RTC Done		3/32P	7/16C	
IN7	1/16P	3/20P			

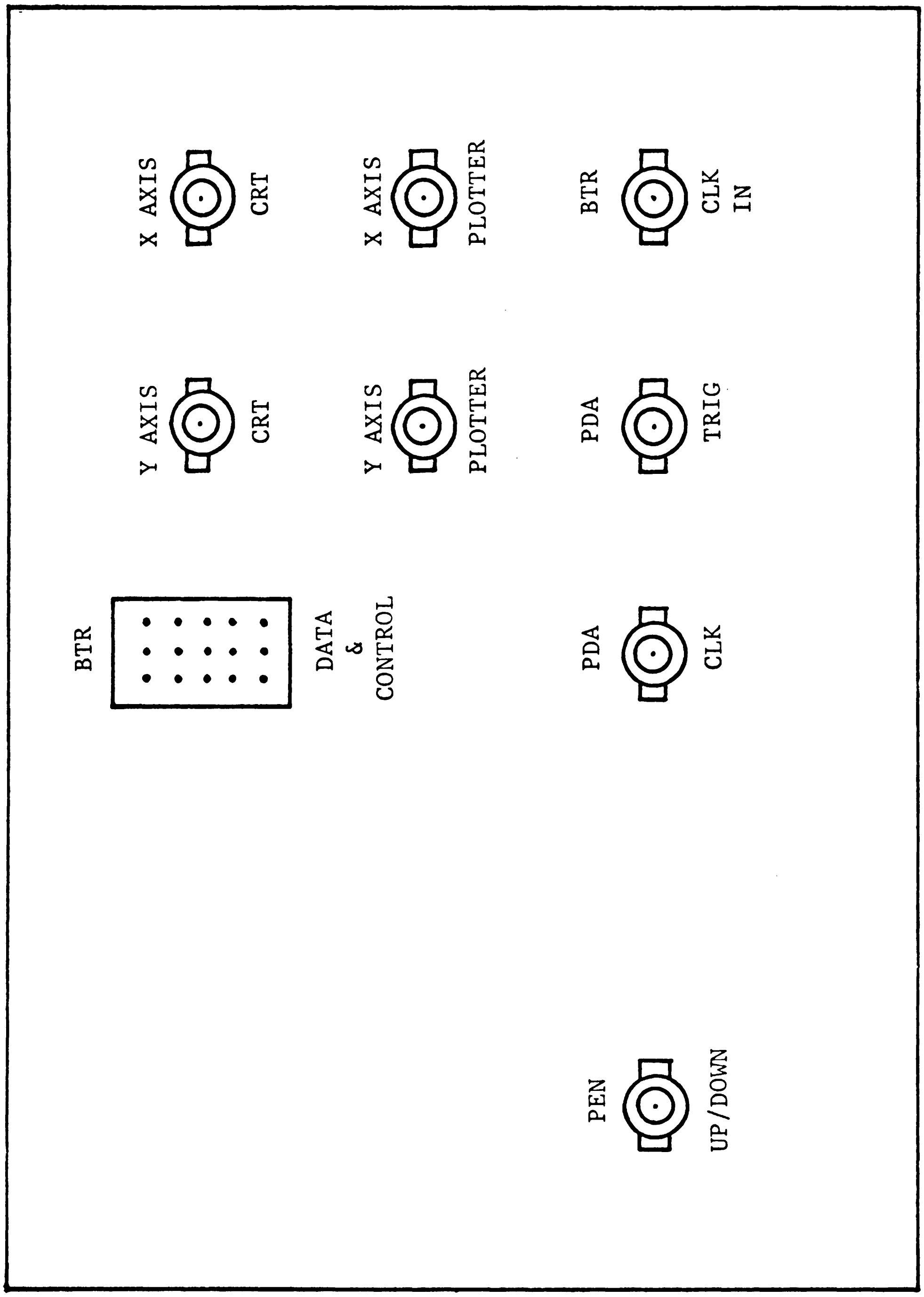
DS4X		3/15C	7/20C	10/14C		13/20P
DSX7		3/18P				13/19P
DSX4		3/15P				
DSX3		3/14P	7/30P			
DSX1		3/12P		10/14P		
DSX0		3/11P	7/19C			
IOP1		3/10P		10/15C		13/22P
IOP2		3/10C	7/14C	10/15P		13/21P
IOP3		3/9P	7/15C			13/23P
IR6	1/40P		7/20P			
NE555 Pot		3/29C and	3/28C			
RC Clock Out		3/27C	7/17C			
Display Clock		7/33C to	16/33C			
Display Reset		7/31C to	16/31C			
Plotter Enable		7/28P (Signal) and		7/27P (+5)		
Pen Up/Down Control		10/25P (Signal) and		10/26P (+5)		
CLK IN (From the Biomation)			BNC to	10/20P		
CLK OUT (To the Reticon)			BNC to	10/31P		
Biomation Arm, Reticon Trig.			BNC to	10/17P	to	Molex 8
Word Command				10/16P	to	Molex 2
Biomation Flag				10/13P	to	Molex 5
Biomation Trigger				10/17C	to	Molex 11

Biomation Data - LSB	10/10P	to	Molex 14
Biomation Data	10/9P	to	Molex 13
Biomation Data	10/8P	to	Molex 10
Biomation Data	10/7P	to	Molex 7
Biomation Data	10/6P	to	Molex 4
Biomation Data - MSB	10/5P	to	Molex 1

YDAC OUTPUT (Analog)	BNC	to	13/13P
XDAC OUTPUT (Analog)	BNC	to	13/12P

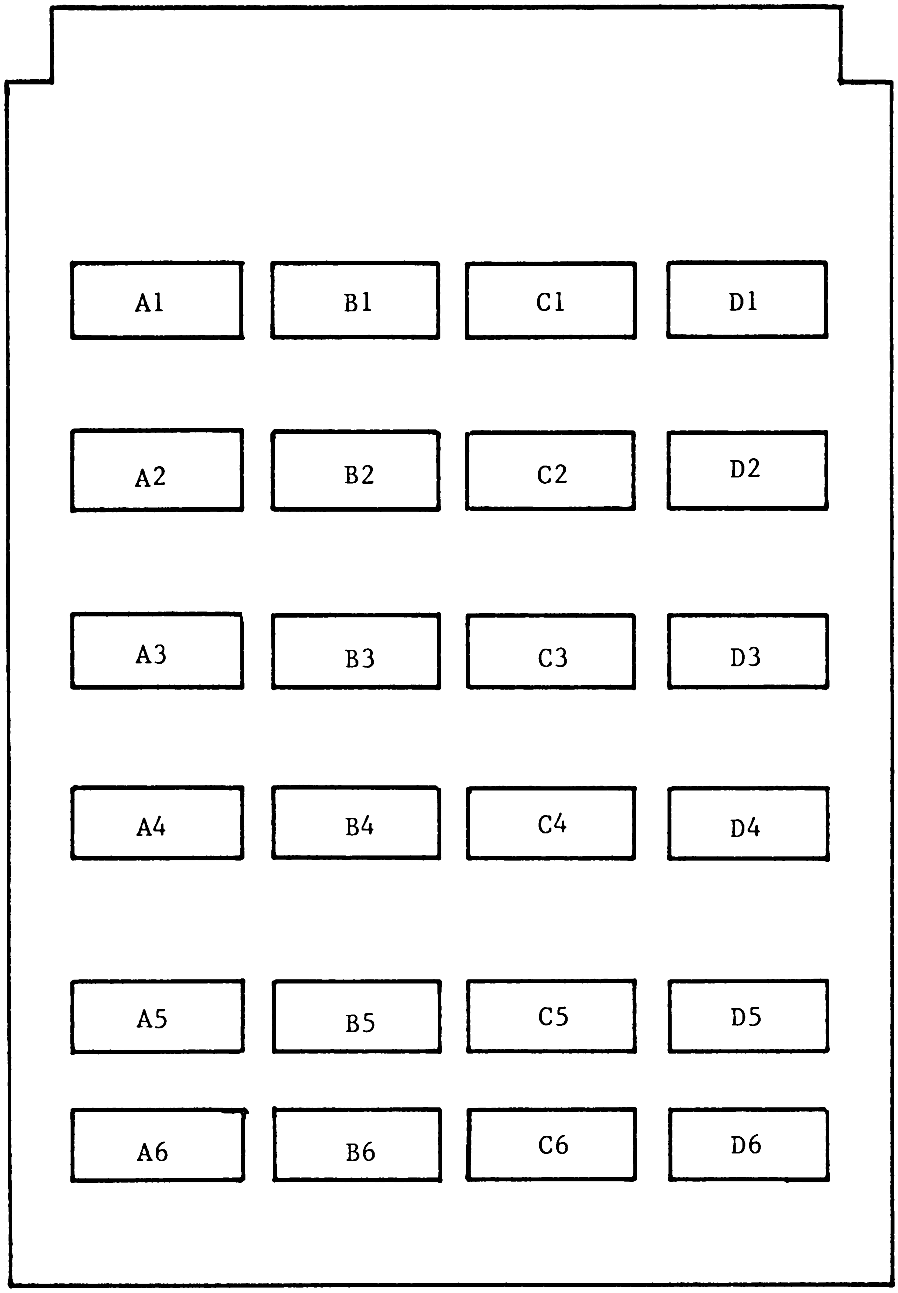
APPENDIX F

INTERFACE ELECTRONICS CONNECTORS



APPENDIX G

PARTS PLACEMENT



APPENDIX H

Biomation Signals to the Interface Electronics

Signal Description	Connector	Burndy	Molex	Interface
Data DØ (LSB)	A	X	14	10/10P
Data D1	D	V	13	10/9P
Data D2	H	S	10	10/8P
Data D3	L	N	7	10/7P
Data D4	P	K	4	10/6P
Data D5 (MSB)	T	F	1	10/5P
Word Command	B	U	2	10/16P
Flag	E	R	5	10/13P
Arm	R	E	8	10/17P
Trigger	U	B	11	10/17C
Ground	W,X	C,A	-,3	To COAX
Biomation Clock	Z-Output*			10/20P

* Not normally available. The Z-Output signal was disconnected and the Biomation clock signal added.

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A MICROPROCESSOR-BASED MULTIWAVELENGTH-
DETECTOR SYSTEM FOR LIQUID CHROMATOGRAPHY

by

Christopher A. Titus

(ABSTRACT)

A multiwavelength-detector system for liquid chromatography was constructed using a state-of-the-art microprocessor and silicon linear photodiode array. By using a microprocessor, the control, data acquisition and data manipulation functions were alterable and flexible towards the optimization of a separation. The computer was used to digitize the analog output of the linear array, subtract the dark current and then correct the data for the non-linear response of the detector and the non-linear emissivity of the light source. These last functions were required due to the single beam nature of the instrument. The entire (200 nm) spectrum could be displayed on a CRT display, the transmittance values of the user selected wavelengths punched on paper tape and plotted as a multi-trace recording on an X-Y plotter. Up to eight wavelengths could be monitored in this manner.

The wavelengths that the computer monitors are user selectable, as is the time between successive spectra (0 to 99 seconds) and the

integration time of the array (the time the light "strikes" the array, typically one to ten msec). The integration time selected depends on the intensity of the light source, a 55 W quartz-halogen lamp, the slit size used in the spectrometer and the sweep frequency, 500 or 50 KHz.

To test the utility of the detector, the reduction of nitrobenzene to azoxybenzene and azobenzene was monitored with the standard single wavelength (254 nm) detector and the computer detector. The results were comparable, but the 254 nm detector was more sensitive. A mixture of commercially available dyes was also separated with a low pressure column with the column effluent routed to the multiwavelength detector.

This work demonstrated that a multiwavelength-detector system could be employed for analytical work. However, due to the low sensitivity of the detector, it will not find as many applications or be met with as much acceptance as the single wavelength 254 nm detector.